A DETAILED REVIEW AND EVALUATION OF METHANE PREDICTION TECHNIQUES AND THEIR APPLICABILITY TO CANADIAN COAL MINES

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TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY

- English
- French

1. BACKGROUND 1-1
   1.1 INTRODUCTION 1-1
   1.2 METHANE PREDICTION 1-2
      1.2.1 General 1-2
      1.2.2 Methane Formation and Retention 1-2
      1.2.3 Methane Flow 1-4
      1.2.4 Release of Methane into Mine Workings 1-8
      1.2.5 Zone of Influence or Gas Emitting Zone 1-16
   1.3 WORK ON PREDICTION TECHNIQUES TO 1977 1-19
   1.4 PREDICTION TECHNIQUES FOR CANADA 1-21

2. CANADIAN OPERATIONS AND CONDITIONS 2-1
   2.1 INTRODUCTION 2-1
   2.2. WESTERN CANADIAN OPERATIONS 2-1
      2.2.1 Smoky River Coal Ltd. 2-1
      2.2.2 Westar Mining Ltd. 2-1
      2.2.3 Other Western Canadian Underground Coal Mines 2-2
   2.3 EASTERN CANADIAN OPERATIONS 2-3
      2.3.1 Cape Breton Development Corporation (CBDC) 2-3
      2.3.2 Other Nova Scotian Coal Mines 2-4
   2.4 SYDNEY COALFIELD 2-4
      2.4.1 General 2-4
      2.4.2 Geological Setting 2-5
      2.4.3 Coal Seam Stratigraphy 2-7
      2.4.4 Roof and Floor Strata 2-9
      2.4.5 Porosity and Permeability 2-10

TABLE OF CONTENTS (Continued)

Page
3. **METHANE PREDICTION TECHNIQUES** 3-1
  3.1 INTRODUCTION 3-1
  3.2 STATUS OF METHANE PREDICTION IN 1977 3-2
    3.2.1 United Kingdom 3-2
    3.2.2 France 3-3
    3.2.3 Belgium 3-4
    3.2.4 Federal Republic of Germany (FRG) 3-4
    3.2.5 Poland 3-7
    3.2.6 U.S.S.R. 3-5
    3.2.7 United States of America 3-8
  3.3 METHANE PREDICTION DEVELOPMENTS SINCE 1977 3-9
    3.3.1 General 3-9
    3.3.2 United Kingdom 3-9
    3.3.3 Federal Republic of Germany (FRG) 3-12
    3.3.4 France 3-14
    3.3.5 Belgium 3-14
    3.3.6 Poland 3-14
    3.3.7 U.S.S.R. 3-17
    3.3.8 United States of America 3-20
  3.4 APPLICABILITY OF PREDICTION TECHNIQUES TO CANADA 3-21
    3.4.1 USA Approach 3-21
    3.4.2 USSR Approach 3-21
    3.4.3 European Approach 3-23
    3.4.4 Canadian Experience 3-23

4. **CANADIAN APPLICATIONS** 4-1
  4.1 INTRODUCTION 4-1
  4.2. CANDIDATE TECHNIQUES 4-1
    4.2.1 Empirical (Analytical) Techniques 4-1
    4.2.2 Computer Simulation 4-2

4.3 SELECTED TECHNIQUES 4-3
4.3.1 Initial Gas Content of Emission Sources 4-3
4.3.2 Degree of Gas Emission 4-4
4.3.3 Gas Emission from the Working Seam 4-6
4.4 DEVELOPMENT REQUIRED 4-6

5. **FUTURE WORK** 5-1
5.1 INTRODUCTION 5-1
5.2 DATA GENERATION 5-2
5.2.1 Gas Content of the Seam being Worked 5-2
5.2.2 Gas Content from other Seam Sources 5-2
5.2.3 Ventilation Surveys 5-3
5.3 RESEARCH AND DEVELOPMENT 5-4
5.4 PROGRAM ELEMENTS 5-5
5.4.1 Gas Source 5-5
5.4.2 Gas Zone and Degree of Emission 5-6

6. **CONCLUSIONS AND RECOMMENDATIONS** 6-1
6.1 CONCLUSIONS 6-1
6.2 RECOMMENDATIONS 6-2

LIST OF APPENDICES

Appendix A Porosity and Permeability Data - Sydney Coalfield
Appendix B Selected Bibliography

LIST OF TABLES

TABLE 1-1 COMPOSITION OF GAS FOR SELECTED SEAMS IN THE UNITED STATES

TABLE 2-1 SYDNEY COALFIELD SEAM SEQUENCE

TABLE 3-1 FACTORS TAKEN INTO ACCOUNT BY VARIOUS PREDICTION METHODS

TABLE 3-2 CALCULATION OF EMISSION FROM SOURCES IN STRATA SECTION

LIST OF FIGURES

FIGURE 1-1	Modes of Gas Flow Through Coal
FIGURE 1-2	Gas Content Versus Depth in the Mary Lee Seam
FIGURE 1-3	Variation of Gas Emission with Shift Tonnage
FIGURE 1-4	Variation of Gas Emission with Weekly Tonnage
FIGURE 1-5	The MRDE Curve for the Degree of Gas Emission from the Worked Seam
FIGURE 1-6	Variations of Stress and Permeability in Strata Above and Below an Advancing Longwall Coal Face
FIGURE 1-7	Degree of Gas Emission from Coal on a Conveyor
FIGURE 1-8	Definitions of the Zone and Degree of Gas Emission for Prediction Methods
FIGURE 1-9	Flow Chart of European Prediction Methods
FIGURE 1-10	Adjacent Seam Gas Emission (%) as a Function of from Distance from the Worked Seam, according to Various Authorities
FIGURE 2-1	Structure Contours, Base of Harbour Seam
FIGURE 2-2	Typical Section for the Phalen Seam in the Lingan Phalen Area

FIGURE 2-3 Typical Section for the Hub Seam in the Prince Mine

FIGURE 2-4 Harbour Seam Structure

FIGURE 2-5 Prince Mine Geology of Resource Block

FIGURE 3-1 Example Presentation of Results from MRDE Prediction Method

FIGURE 3-2 Zones of Emission used in FRG

FIGURE 3-3 Degrees of Gas Emission in Roof and Floor

FIGURE 3-4 Degree of Gas Emission Function for MRDE Prediction Method

FIGURE 3-5 Principle of Firedamp Drainage Calculation

FIGURE 3-6 Predicted Gas Emission for Seams in Roof and Floor Strata

FIGURE 3-7 Permeability Isobars - USA

FIGURE 3-8 Permeability Isobars - USA

FIGURE 3-9 Permeability Isobars - USA

FIGURE 3-10 Relationship between Methane Content in Coal and Volatile Matter Content (in%)

1. according to Schulz, 2. according to Winter,
3. according to Stuffken, 4. according to Barbara Experimental Mine

FIGURE 3-11 Methane Emission Rate Versus Age (Depth) of Mine
FIGURE 3-12 Methane Emission Rate Versus Age of District
FIGURE 4-1 Comparison of Initial Content and Actual Emission - USA
FIGURE 5-1 Work Program for MRDE Prediction Technique

EXECUTIVE SUMMARY

Emission of firedamp into working areas in underground coal mines is known as a major safety hazard. In recent years this hazard potential has been heightened by the increased rates of extraction and levels of production achieved with modern mining methods and equipment. To combat this potential for explosion resulting from methane emission, it is essential that the methane concentrations in the ventilating air current do not exceed acceptable limits.

To contain the methane emission hazard, ventilation engineers must plan to ensure adequate quantities of air are delivered to strategic zones in the mine workings and, where necessary, supplement this with effective methane drainage. The ability to predict methane emission volume is a vital element in the ventilation planning process.

Methane prediction techniques have been developed in a number of major coal producing countries. These techniques were developed to accommodate the site specific conditions resulting from the constraints imposed on the methane release mechanism by the physical characteristics of the coal being mined, the local geological environment of the seams and the mining method employed. As the techniques have been refined and technical information has been exchanged, the methods of prediction have become more aligned. However, some differences in the physical models will always exist to accommodate local circumstance. Techniques based on physical modelling are now sufficiently developed to provide acceptable levels of accuracy in methane prediction.

In Canada, work has been done over a number of years on the methane content of coal seams but there has been no concerted effort to develop a prediction technique. However, with underground coal extraction now being concentrated in the Sydney Coalfield, it is opportune to develop a Canadian prediction technique. Given the geological setting of the Coalfield and the

use of modern longwall methods of coal extraction, a prediction technique modelled on longwall mining in a multiple seam environment would provide a suitable base for the development of Canadian prediction methodology. Most European prediction techniques have been developed in longwall mining environments and, as such, appear appropriate for Canadian requirements. The majority of the European methods have developed from practical experience aligned with the measurement of actual emissions. However, the technique used in the United Kingdom is based on a coherent physical theory (Airey). It uses a comprehensive physical model and has been developed in a geological environment where the coal seams have extensive lateral continuity and relatively consistent thickness. As such, it appears to provide a suitable basis for the development of a Canadian methane prediction technique.

To apply the United Kingdom technique, a comprehensive data base must be established. Very little data is in existance for the Sydney Coalfield relating to the physical structures of the coal seams and surrounding strata and this data base needs to be developed. Concurrently existing ventilation data should be reviewed in relation to the emission parameters included in the physical model. This examination of existing information should precede any detailed laboratory and in-situ test programs. Subsequent research and development can then be directed to enhancing the information base and providing a comprehensive physical model for the application of an effective Canadian methane prediction technique.

SOMMAIRE

Le dégagement du grisou dans les chantiers des mines souterraines de charbon est reconnu comme étant un danger majeur. Ce danger s'est accrue ces dernières années par suite d'une augmentation des taux d'extraction et des niveaux de production atteints grâce a l'équipement et aux méthodes modernes d'exploitation. Afin de lutter contre le danger possible d'explosion provenant de dégagement du méthane, il est nécessaire que les niveaux de concentration du méthane dans l'air circulant dans les systèmes de ventilation ne dépassent pas les limites tolérables.

Dans le but de maîtriser le danger que représente le dégagement du grisou, les ingénieurs en ventilation doivent prendre les mesures nécessaires pour que des quantités adequates d'air soient amenées aux zones stratégiques et que là où c'est nécessaire, un "drainage" effectif du méthane soit ajouté a ce système. La capacité de prédire le volume du dégagement du méthane représents un élément vital dans le procédé de plannification de la ventilation.

Dans plusieurs pays producteurs de charbon, des techniques de prédiction de dégagement du méthane ont été développées. Elles peuvent être adaptées aux conditions spécifiques d'un chantier donné, conditions qui dépendent des contraintes imposées sur le méchanisme d'échappement du méthane par les propriétés physiques du charbon miné, le milieu géologique des couches et les méthods d'exploitation minières employées. De meilleures méthodes de prediction coïncident avec le développement de meilleures techniques et de meilleurs échanges d'information. Cependant, parce que les conditions locales varient, des différences existeront toujours dans les caractéristiques physiques des prototypes. Des techniques de prediction de méthane basées sur certains prototypes sont maintenant suffisamment développées pour fournir des niveaux de précision admissibles.

Au Canada, un certain travail a été fait ces dernièrs annés sur la teneur en méthane des couches de charbon mais il n'y a pas eu d'effort concerté

pour développer une technique de prédiction. Cependant, puisque l'extraction souterraine se concentre maintenant dans le champ de charbon de Sydney, il serait à propos de développer une technique canadienne de prédiction. En tenant compte de l'aspect géologique du champ de charbon de Sydney et de l'emploi de méthodes modernes d'extraction à longue taille, une méthode de prédiction modellé sur une exploitation minière à longue taille dans un milieu à couches multiples fournirait une base appropriée au développement d'une méthodologie canadienne de prédiction. La plupart des techniques européennes ont été développées dans des exploitations à longue taille. Elles pourraient donc être appropriées aux exignences canadiennes. La majeure partie des méthodes européenes se sont développées à partier d'une expérience pratique de concert avec des mesures de dégagement réel du méthane. Toutefois, la technique en usage dans le Royaume-Uni est basée sur une théorie cohérente, celle d'Airey. Elle utilise un prototype physique compréhensif et elle a été développée dans un milieu géologique où les couches de charbon ont une continuite laterale exptensive et une epaisseur relativement constante. Il semble donc que cette technique fournirait une base adéquate au développement d'une technique canadienne de prédiction.

Afin d'appliquer au Canada la technique en usage au Royaume-Uni, une base de donnés détaillées doit d'abord être etablie. En ce qui concerne le champ de charbon de Sydney, très peu de données existent actuellement en ce qui a trait aux structures physiques des couches de charbon ainsi que des couches avoisinantes et il est important que cette base de donnés soit développé. Simultanément, les présentes données sur la ventilation devraient être revisées par rapport aux paramètres de dégagement du méthane inclus dans le prototype. Cette revue de l'information existante devrait précéder tout autre programme ou test in-situ et en laboratoire. Des recherches et des développements ultérieurs pourraient alors être orientés de manière à accroître l'information de base et à fournir un prototype physique qui amènera l'application d'une effective technique de prédiction du méthane au Canada.

SECTION 1

BACKGROUND

SECTION 1

BACKGROUND

1.1 INTRODUCTION

The design, development and working of an underground coal mine is influenced by a number of physical criteria, each of which must be fully addressed to ensure a viable unit.

One major element is the level of production required from each mechanized unit. Current economic constraints are such that large-volume, concentrated production has become a necessity. Modern mining equipment can produce the large volumes of mineral required but, in doing so, can also release large volumes of methane into the mine workings. To keep these methane concentrations below the specified safety limits at all times, requires the provision of sufficient quantities of air supplemented, where necessary, with efficient methane drainage. Engineering effective mine ventilation in these circumstances is greatly aided by the ability to reliably predict methane production through all phases of the operation.

Formerly, predicting the volumes of methane that would be generated during the extraction of any given coal seam was, to a large extent, a function of local knowledge. More recently, practical methods for determining the gas content of coal seams have been developed and when used in conjunction with predictability software, they allow computer simulation of methane release in relation to the mining method and levels of productive capacity.

A number of mining countries have developed models for methane prediction. Several techniques were reviewed in an IEA Coal Research Report, "Methane Prediction in Coal Mines" (S.J. Curl, 1978). Further development work has continued and some of this is applicable to Canadian coal mines.

It is necessary to review the elements involved to develop a methane prediction technique for Canadian coal mines, and relate them to existing Canadian coal mining conditions.

Given this basic model, an appropriate technique can then be developed by analysis of the current state-of-the-art and assessment of the elements which relate to Canadian conditions.

1.2 METHANE PREDICTION

1.2.1 General

To predict methane emission, it is necessary to understand the physical system within which the methane is retained, the mechanics of release and the extent of the release zone.

Factors affecting methane prediction are described in the following sections.

1.2.2 Methane Formation and Retention

The geological factors that have an effect on methane emissions are all those that affect both the transmissivity of gaseous fluids through coal and the surrounding strata and the flow paths that those gases may follow.

Methane in coal is a by-product of the coalification process (Raistrick, 1939). The most important products of this reaction are the gases (Kim, 1974). Methane results from the aerobic bacterial metabolism of cellulose, lignin, wax, and resins. This process takes place in three stages (Deul, 1964):

1. The cellulose ferments, forming mostly carbon dioxide, hydrogen, and methane. As the decomposing vegetation is exposed, either to water or air, most of the gas is released to the atmosphere.

2. There follows a slow decomposition of lignin in circumstances in which a sediment may have accumulated over the deposit to allow the presence of moisture, but not of air. Differential diffusion in this stage allow carbon dioxide to be adsorbed by the water. Hydrogen is diffused through the sediment to the atmosphere, and the methane remains in the coal.

3. In the final state, methane is prevented from escaping by burial and is trapped in the coal. With increasing pressure at depth and lack of complete impermeability, some methane escapes while some is contained within the roof and floor rock (Perry, 1960). The result is a coal with high methane content relative to carbon dioxide, hydrogen, and other gases.

Bromilow, et al. (1961) state that even at the present stage of fossilization, methane and hydrogen are still being produced slowly but steadily at a rate inversely proportional to the age of the coal deposit. They contend that much more gas has been produced than is presently found in the coal.

Normally, up to 98 percent of the gas emitted from coal is methane. The remainder is made up of inert gas, some higher hydrocarbons, nitrogen, and occasionally a trace of carbon dioxide (Kim, 1973). Table 1-1 shows the composition of gas from a number of seams in the United States.

The methane present in the coal exists in two states—the free gas state and the adsorbed state. The free gas is compressed in the fractures and micropores of the coal, but the adsorbed gas adheres to the larger internal surfaces of the coal. The larger proportion of the gas is currently considered to be adsorbed (Bertard, 1970). Daines (1968) has found that the amount of gas in the adsorbed state at a pressure of 2.07 mN/m^2, which is a reasonable pressure for a seam between 200 and 250 m deep, is 10 times as great as the amount of free gas. The methane in a coal seam is often under pressure as high as 6.89 mN/m^2.

The process of adsorption under pressure is reversible. Methane in the coal is released when the pressure is reduced and is the main reason for the flow of gas from the seam into working sections. The flow rate depends on the difference between the pressure of the gas in the coal and that of the air in the mine entry (pressure gradient).

Methane is also known to occur in shale, sandy shale, porous sandstone, and in bedding planes, which appears to be the case in a number of European mines, more so than in United States mines.

1.2.3 Methane Flow

Porosity

The migration of gasseous fluids is influenced most strongly by the coal's fracture density and geometry. Although intact coal has a measurable porosity, the size of the pore spaces (generally about 0.5 nm) is too small to provide for significant transmission of fluids; the effective porosity is the fracture porosity of a coal seam. Much of the methane emitted at working faces orginates in a high-permeability, relaxed or fractured zone, which extends into the coal being worked and also into adjacent roof and floor strata, whether that strata contains coal or not. These fractures are a combination of mining induced failure planes and naturally occuring features such as joints, faults, and most importantly coal cleat. The term cleat is simply the name used for joints occuring in coal and the formation of a cleat is believed to be produced by exactly the same factors which produce joints in the surrounding strata. The geometry of any cleat pattern is consistent with the equivalent joint pattern in the surrounding strata, with the exception that the mechanical properties of coal are different from those of most other soft sediments. This factor can produce apparent differences between equivalent cleat and joint sets. Usually the most apparent difference between equivalent cleat and joint sets is a significant difference in the fracture density.

On occasion fractures are found in coal seams which do not appear to be related to the patterns of jointing observed in the surrounding strata. These coal fractures may be related to a locally developed fracture system in the surrounding rock that does not technically qualify as a joint system. In other cases there may appear to be no direct equivalent to this coal fracture system in the surrounding rocks. Usually the geometry of these coal fractures indicates a direct relationship to specific events of deformation resulting from tectonic events or differential compaction. Present concepts for the production of joints does not allow these coal fractures to be classified as a cleat. Fracture systems such as this do however contribute to the overall fracture porosity of a coal seam.

Based on investigations of jointing and cleats in eastern and western U.S. coalfields, McCulloch, et al (1975) concluded that:

"Cleat in the bituminous coalbeds is formed by local structural force rather than by internal forces within the coal such as result during diagenesis and compaction. The face cleats tend to be perpendicular to the axial trend of the folds and probably formed as extension fractures. The butt cleats tend to be parallel to the axial trend and formed after compressive forces were released."

An elaborate discussion of the theoretical considerations for the formation and frequency of joints in rocks of different thickness and lithology and which display differing amounts of tectonic deformation is presented by Price (1966). The extent to which pore water pressure may affect the development of those fractures is discussed by Secor (1965).

The face cleat is a system of extension fractures formed after structural deformation during the process of uplift and crustal extension. Commonly the face cleat shifts orientation to maintain a perpendicular relationship to the axial trend of local structures. The face cleat is generally more well developed; usually they are laterally more continuous and more frequent than the butt cleat. The face cleat is more likely to cross bedding planes within the seam.

In most reported investigations of cleat that address coalfields subject to only minor folding, the face and butt cleat have an approximately perpendicular relationship to each other.

Numerous field studies have shown that the frequency of face or butt cleat development is related to the mechanical properties of the seam and its contained plies. A discussion of the theoretical considerations pertinent to this feature is provided by Price (1966). General observations from numerous seam exposures show that the change in frequency of either face or butt cleat is easily seen in coals of varying lithotype; bright bands of coal tend to have a much higher cleat frequency than do lithotypes that appear dull. A striking example is reported by MacRae and Lawson (1954), who observed that for several seams in the Yorkshire coalfield durain bands thicker than six inches have less than five fractures per foot, whereas clean, bright coal bands have 70 fractures per foot. It is important to realize, therefore, that while the frequency of the face cleat and butt cleat may vary significantly in any one coal type, changes from one lithotype to another tend to produce proportionally greater changes in both the face and butt cleat.

The preceeding discussion indicates that the fracture porosity will vary with the lateral extent of any cleat surface and the frequency of those cleat surfaces. It also indicates that the fracture porosity will be greater in coals that display a high proportion of bright coal plies.

Permeability

In coal, permeability is found to depend strongly on the type of coal and on the amount of water in the seam. The unfractured "solid" coal has a very low permeability according to Kissell (1972), and this has the effect of limiting the flow of gas into the mine; but many bituminous seams are highly fractured. Hence, in coal seams, even though the actual permeability may be low; as a result of the fracture system a "second permeability" exists allowing the gas an avenue of escape. The actual permeability of a coal can now be measured using Darcy's equation for unsteady-state flow as it was established by Airey (1968). This has greatly helped in understanding the flow of gas in coal seams.

With respect to permeability of coal seams, the naturally occurring fracture geometry requires comment. The nature of the face and butt cleat suggests that a lateral asymmetry exists due to differences in the lateral extent and frequency of fractures in each cleat system. This condition applies to some extent in all cases, but a particularly friable coal can show an unusually low asymmetry.

In many coal seams a preferential direction of fluid flow exists within the seam. The asymmetrical directional permeability or permeability anisotropy is directly related to different character of the face and butt cleat. The face cleat is usually the more permeable fracture system because of the greater lateral extent of individual fractures and because there tends to be a higher frequency of face cleat planes than butt cleat planes.

Gas flow into a coal mine is a two-step process (Gunther, 1965 and Kissell, 1975). In the first step, gas flows from lumps of unfractured, solid coal into the fractures that delineate these lumps. The lumps may be deep within the coal, or they may be close to the excavation. In the second step, the gas flows through the fractures into the mine (Figure 1-1).

Fisekci (1975) studied the flow of gas into mines in Alberta and related this to previous work by Hargraves in that Darcy's Law and Fisk's Law describe the flow of gas through coal.

1.2.4 Release of Methane into Mine Workings

For all practical purposes, in the undisturbed coal seam a steady state exists between the retained gas and the prevailing pressure. With mining, this equilibrium is disturbed such that a three-dimensional zone of influence is formed around the mine working. This zone has boundaries which extend beyond those of the immediate mine working and these boundaries are finite. The limit of the zone of influence is dependent upon two major factors, namely; local geological features and mining conditions and methods.

Local Geologic Features

A number of geologic factors play a role in the release of methane into underground excavations. The exact effect of the majority of these to be discussed is still unknown, but that they have some effect is admitted by most scientists who feel that each plays a minor role in the emission and release of methane. Their overall effect, however, may be appreciable.

Cleat

As stated previously, **cleat** in coal is related to tectonic forces. In the Pittsburgh seam it is found that the permeability is greatest in the face cleat direction. Measurements by Parson and Dahl (1971) in strata adjacent to the Pittsburgh seam showed that the major lateral compressive stresses occurred in an east-west direction, nearly perpendicular to the butt cleat direction. They concluded that the butt cleats are squeezed more tightly, thus reducing the permeability.

These observations show the importance that cleat plays in determining "directional permeability" and therefore, the flow of gas through the coal. Any horizontal drilling in mines to degasify an area must take into account the preferrred flow due to directional permeability. Kissell (1972) reported on tests that showed that a hole drilled into the coal seam perpendicular to the face cleat could yield from 2.5 to 10 times as much as a hole drilled perpendicular to the butt cleat.

Faulting

In some cases, gas is trapped by **faulting** and in other cases the fault plane allows the gas to escape. McCulloch (1975) noted two such cases; the first in the Lucerne No. 6 Mine in Pennsylvania where a low-angle thrust fault caused high emission of gas and water into the mine, forcing sections to be abandoned for a few days until the gas emitted had been diluted to a safe working level. A second case in the Pocahontas No. 3 Seam in Virginia involved a strike-slip fault in a very gassy coal mine. Here, little or no gas was encountered for up to 91.4 m on either side of the fault zone.

Willett (1964) pointed out that in recent outbursts in the Silkstone Seam in Yorkshire, about half the cases had faults existing within 91.4 m of the outburst although one had occurred when no fault was present for 640 m. He also found that it was not significant whether the fault was normal or reverse, or whether the seam was inclined.

The outburst of methane which occurred in the Yorkshire Main Colliery in the United Kingdom in 1976 demonstrated how a zone of faulting can allow gas to enter the workings from a seam other than the one being mined. In this case a sudden large emission of methane created an extremely hazardous situation.

Folding

Fracturing in coal is related to **folding**. The fracture planes are surfaces along which gas travels. The folding can also affect gas emission through its effect on water flow. Recently it has been found that a dip of one degree can decrease the flow of gas.

Alpern (1970) noted that in the areas he studied, gas was found in the crest of anticlines at depths as shallow as 85 to 100 m and synclinal structures were free of gas at depths of 300 to 400 m in the same area.

Dip

For many years the **dip** of the strata was not thought to play a significant role in the migration or flow of methane. Experience with descensional ventilation systems has led to a better understanding of its effect.

These experiences show that, although the change from ascensional to descensional ventilation does not increase the total methane emission, it does affect the gas flow paths in surrounding strata and therefore affects the location of the points of issue.

Bromilow (1958) postulated that in the strata above a longwall face area there is a zone of influence. The height of the zone of influence is related to the ventilation pressure across the face, the strata permeability and the gas emission rate. In addition, other important factors are the seam inclination and the direction of ventilation relative to the gradient. The air passing through an inclined face and the methane in the overlying strata form two interconnected columns of gas, one having twice the density of the other. Hence, a natural ventilation pressure difference of 249 N/m^2 per 45.7 m is created. If a descensional ventilation system is used and the ventilation pressure difference is less than that due to the buoyancy effect of methane, then methane will migrate up the gradient into the intake roadway. Further studies of gas-flow patterns indicate that with descensional ventilation, the gas ceiling in the roof strata is likely to be nearer to the excavation, which means that gas may be an increased problem near to the face in both intake and return roadways.

Other investigators have reported on the effects of seam inclination. According to Brown (1963) its main effect is in redistributing the points of gas issue. Alpern (1970) and McCulloch (1975) indicate that dip may have an influence as a result of the need for the gas to displace water. This was thought to be more important in high and medium volatile coals due to the greater cleat spacing.

Nature of Strata

The **type of strata** above or below the coal has been found to play a very important role in the emission of gas into the mine workings. The exact effect on the amount of gas emitted from this strata differs in each case and is very much dependent on the seams contained therein. Willett (1964) noted that a usual feature of floor outbursts in some English mines was that the seams were underlain by an impermeable rock layer below which was a permeable or porous bed. He found several cases in which the strong rock layer varied in thickness or distance beneath the seam being worked. Because of these differences, mining could result in fracturing of the strong impermeable bed allowing gas from below to migrate up through it into the mine workings.

The presence of **numerous seams** in the immediate roof and floor strata in many mines of Continental Europe has led to the conclusion that as much as 90 percent of the gas emission associated with the working of a seam originates from these seams.

Winter (1953) cited data that showed that a seam with a sandstone roof had a decreased rate of gas emission in the return when compared to a shale roof. In the former case, however, the duration was increased. But he also pointed out that the emissions from the seam could increase with a sandstone roof due to the greater cantilever formed which would cause more pressure on the coal. It was also noted that when a strong impermeable bed of rock exists between the seam worked and another seam, there is a danger of sudden, abnormally high emissions from the other seam. Because the impermeable bed fractures at infrequent intervals it can emit a large amount of gas into the mine over a very short period of time.

McCullouch (1973), in a study at the Cambria Mine in Pennsylvania noted that during the development of room-and-pillar mining, the mine had no significant problems with gas emission but when retreating and pulling pillars, allowing the roof to fall, the gas emission constantly reached critical limits. A further investigation showed that another seam located approximately 9m above that being worked was very gassy and when the roof caved, it did so up through this seam allowing the gas trapped in it to migrate into the workings below.

Popp (1976) stated that methane emission from the Beckley Seam in West Virginia came not only from the coal but also from adjacent strata. He noted a porous and permeable sandstone either above or below the coal which allowed methane to enter the mine atmosphere from external sources such as rider coals, splits, and carbonaceous shales.

Alternatively, other experiences have shown excessive methane emission rates occur during the development of a seam for extraction by longwall retreating faces, while the problems during the subsequent **longwalling** have been minimal.

Depth of Seam

The effect of **depth** on gas emission from a coal seam is a factor that is not completely understood. Experience indicates that the gas content of any given seam increases with depth.

Brown (1963) noted that depth will affect the gas content of a seam in any one specific area but Jeran (1976) completed a study that revealed that within a given mine the daily emissions of methane did not correlate with depth but with the length of rib exposed.

Diamond (1976), in a study in the Mary Lee Seam in Alabama, indicated that there was much more gas trapped in the coal as the depth increased. The coal also changed rank from a high volatile bituminous coal at outcrop to a low volatile bituminous coal at 609 m. Figure 1-2 shows how the gas content measured by the direct method of Kissell (1973) and McCulloch (1975) increased as the overburden depth increased. Similar results have also been found for the Pittsburgh Seam in Pennsylvania and the Hartshorne Seam in Oklahoma.

Work on geologic features of coal seams and surrounding strata highlight their importance in methane prediction. Some features are present in all seams and mine layouts should take account of these. Others are present only intermittently and accurate prediction must account for their effect when they do occur.

Mining Conditions and Method

The equilibrium that exists in the strata between rock pressure, gas pressure, and rock strength is completely disrupted when an excavation penetrates it. The strata are originally in equilibrium under the action of a major vertical pressure with complete restraint in both lateral directions (Brown, 1963). Any excavation removes this lateral restraint. Also, the weight of the strata over the mine opening has to be transferred to the sides, which raises the vertical pressure.

The existence of a relaxed zone around an excavation has been noted by strata control investigators over many years. Brown (1963) noted that the creation of a mine opening would result in adjacent zones of relaxed rock surrounded by a region of increased pressure. The many fractures in the relaxed zone give rise to a region of much higher permeability in which the pressure gradients are also increased greatly. Therefore, the emission of gas from any strata within this zone is increased. Both the pressure gradients and the resultant permeability of the coal and associated strata are affected.

Bromilow (1961) stated that measurements made in Great Britain in connection with strata control showed that as the stress or pressure was reduced, the coal and rock expanded, cracks and fissures were formed, and there may have been some disintegration of the coal as it was crushed. All this he felt increased the permeability of the coal and strata to the flow of methane.

Not only do mining conditions affect the methane emissions in a mine, but also the mining method plays an important role.

Before the introduction of continuous miners and longwall power loading equipment, the underground gas emissions which could not be diluted to a harmless mixture by increasing the flow of ventilating air occurred in only a few very gassy mines. In areas where methane emissions were excessive, mining was often discontinued until the methane could be diluted to a harmless concentration. Down-time caused by gas accumulations resulted in loss of production in these areas, but often other producing areas of the mine increased production to offset the loss. To some extent, this is still done but, with the larger, deeper mines using more intensively worked sections, replacing production in this way is not tenable and accurate methane prediction is at a premium in these circumstances.

Merritts (1963) stated that the introduction of continuous mining machines into room-and pillar layouts created two additional problems. These were:

- The rate of extraction was more rapid, and therefore, the gas emissions were usually increased, which required greater quantities of ventilating air to dilute the gas and
- The bulk or size of the continuous miner virtually precluded the continuous flow of air across the face, so allowing pockets of gas to accumulate.

A third problem was pointed out by Patching (1970) when he noted that the additional comminution produced by machine mining could increase the emission rate.

Longwall faces also experience similar problems. The effects of multi-shift coal production on gas emission rates have been investigated by Joliffe (1970). He found that the anticipated emission from intensively worked faces, as predicted from observed emission rates on faces producing on one shift per day, did not materialize. His results indicated that the emission rate per tonne decreased with increasing shift, daily and weekly output (Figures 1-3 and 1-4). In effect, the degree of gas emission reduced with increasing rates of extraction, a significant factor in subsequent prediction work.

Various workers have investigated ventilation and methane flow paths on longwall faces, especially in the vicinity of power loaders. Particular attention has been paid to the difficulties associated with adequately ventilating high-output retreating faces where specific problems have been identified at the return end of these faces (Moore, 1976).

Morris (1961) noted that the mining of coal in a longwall face causes fractures to occur in the strata above and below the extracted seam. Observations behind advancing faces have detected deformation and crushing in the gate roadways that allow gas from lower seams or strata to migrate into the mine workings.

Brown (1963) completed a study that showed that the gas emission in the intake gate was usually much less than on the face and the inbye part of the return airways. He also noted that the emission increased during mining of the coal and did not stop with the cessation of operations but gradually decreased over a period of time. This was also found by Cetinbas (1972) from studies in coal mines in the United States. Other investigators have reported the continued emission of gas from mines and old workings over many years.

In attempts to combat the problems associated with high emission rates from intensively worked longwall faces, a wide variety of mining layouts have been designed. The traditional solution of increasing ventilation flow where methane problems existed is no longer the sole answer. Various split methods of ventilation are available for use with advance, retreat, advance-retreat, and semi-retreat layouts. The extent to which these alternative layouts are able to deal with the anticipated problems is a major consideration prior to a decision to use methane drainage techniques.

1.2.5 Zone of Influence or Gas Emitting Zone

As a result of the comprehensive studies on methane emission over the years, investigators now generally accept that the shape of the zone of influence (Gas Emitting Zone) generally equates to a rectangular prism with its boundaries lying beyond those of the immediate working in each direction.

In the case of the lateral boundaries, their location is rarely more than 15 metres into the adjacent pillar on each side of the working, hence their location is relatively simple to determine.

The vertical boundaries of the zone are much more complex. In its most simple case the boundary below the worked seam would not be more than 40 metres, however, in multi-seam workings this distance can easily be exceeded. In the case of the roof boundary, for longwall working it should be anticipated that it will depend upon the face geometry. For room and pillar working, where stress relief is much less, the roof boundary of the zone will be much closer to the immediate working. In all cases, local geology will have an effect on these boundaries.

Accurately judging the geometry of the zone of influence, together with its relationship to the actual release of methane, is essential for reliable methane emission prediction. If predictions on methane emissions are to be made with any accuracy, the dimensions of the zone as it relates to the face geometry and method of work must be identified. One other important parameter in considering the zone of influence in longwall working is face length. Face length will influence the horizon at which the roof boundary of the gas emitting zone lies because the volume of the zone of emission is also increased. This boundary will extend upward as face length increases. Therefore, it follows that the longer the face the larger the gas emitting zone and therefore the greater the gas emission per unit of time for a given rate of extraction.

To predict methane emission, each potential source of gas within the zone of influence must be considered.

The Coal Front

Methane is released from the **coal front** of the working face by the way of two distinct mechanisms and each is influenced by the natural permeability of the coal. First, the effect of sudden comminution of the solid coal by a power loader will result in a peak of methane emission moving with the machine as it traverses the face of the working. The rate of emission through this mechanism will depend upon:

- The degree of comminution or degradation of the coal. (The greater the proportion of dust and small particles, the greater will be the coal front gas from any given seam.)
- The initial gas content of the coal.
- The initial pressure of the adsorbed gas.
- The rate of production from the operation.

Secondly, gas will be emitted from any standing face. The rate of emission decays with time and depends upon:

- The initial gas content of the coal.
- The pressure gradient.

- Cleat orientation.
- The inherent and mining-induced permeability.

In addition to the above, on any active face the make of methane from the coal front is directly proportional to the rate of advance. The rate of advance is perhaps the most significant of the variables in the prediction process. Figure 1-5 shows the degree of gas emission with respect to rate of advance for a typical bituminous coal face. (Dunmore, 1980)

The Floor Strata

The degree and amount of gas release from **floor strata** depends upon the presence and proximity of coal seams and the permeability of the strata. For this strata, a distance of 100 m below the seam being worked is usually recommended to take account of all mining variables.

The Roof Strata

The upper **limit of the zone** of influence is considered in longwall workings to be 200 metres for prediction purposes. Investigators in West Germany have reported zones of influence extending to over 300 metres above the worked face (Noack and Janas, 1984). Figure 1-6 illustrates the migration of methane from gas-bearing strata in the roof and floor adjacent to longwall workings. Figures 1-6 also shows the effects of the front abutment stress just ahead of the faceline.

Coal in Transit

Coal in transit from the face continues to give off methane. Again the rate of emission will be higher for the small particles of coal. Figure 1-7 (Dunmore, 1980) shows a typical variation of gas-loss with respect to time spent on a conveyor in an average working district. The gas emission shown in this figure is expressed as a percentage of the residual gas content at the time of shearing the coal on the face. This residual content is deduced from Figure 1-5.

1.3 WORK ON PREDICTION TECHNIQUES TO 1977

Organizations in several countries have developed techniques which enable the flow of methane into coal mine workings to be predicted. The three main geographical areas of prediction activity are Western Europe, Eastern Europe and Continental North America and their development programs were comprehensively reviewed by S.J. Curl in the 1978 IEA Research Paper.

The European methods used the same basic approach and were aimed specifically at longwall operations. The parameters investigated were those addressed in the previous section of this report, namely:

- the stratigraphy above and below the worked seam,
- the desorbable gas content (m^3/ton) of the worked seam, adjacent seams and strata,
- the zone of gas emission in both the roof and floor strata,
- the degree of gas emission from adjacent seams and strata within this zone of emission.

A detailed knowledge of the strata surrounding the worked coal seam is an essential element in all prediction techniques because testing in many site specific cases has demonstrated that as much as 90% of the emitted gas comes from these sources rather than the seam being worked. The extent of the stratigraphic column investigated is dependent upon the individual assessment of the **Zone of Gas Emission.** This zone is the three-dimensional volume from which gas is released into the workings, or methane drainage system, as a result of mining operations. The **Degree of Gas Emission** is the percentage of gas contained in the strata at any specific level, that will flow into the mine workings.

The prediction methods developed in individual countries differ both in definition of Zone of Gas Emission and Degree of Gas Emission within that zone. However, most methods define variations of degree with height within a zone which was represented by a rectangular prism as shown in Figure 1-8 (S.J. Curl, 1978).

Each method requires knowledge of the gas content of all seams and strata within the zone. As this is rarely available because initial exploration programs have been inadequate with respect to the assessment of methane, calculations are based upon:

- the gas content of the worked seam,
- the assumption that other coal seams in the zone have the same content as the worked seam (except where measurements were available),
- the assumption that intervening strata has a percentage of the coal seam gas content.

Methane emission for all of these prediction methods address a combination of three gas sources:

- the seam being worked,
- adjacent seams and strata,
- coal in transit.

Figure 1-9 details the methods of calculation used to obtain the total emission of gas.

The degree of gas emission is calculated for seams and strata adjacent to the seam being worked. Each bed is considered separately and related to its distance from the seam being worked. The mathematical and graphical procedures for these determinations are shown in Figures 1-8 and 1-10.

Relative Thickness relates the methane emission from the adjacent seams and strata to the coal produced in the seam being worked. It is the ratio of the thickness of each seam and stratum to the thickness of the worked seam. This ratio is multiplied by the gas content of that seam or stratum to give the methane emission per tonne of coal produced from the working face. The summation of the individual methane quantities gives the total predicted volume of methane emitted from adjacent seams and strata.

Methane emission from the seam being worked is derived by applying a percentage factor to the gas content of the worked seam. Initially this was assumed to be 100%. However, as prediction techniques improved, emission percentage was related to mining parameters; the most notable parameter being the rate of face advance.

Gas emission during coal clearance is related to the time it takes for the cut coal to leave the working section. The residual gas content of the coal is used for this calculation.

The total gas emission is the summation of emissions from the elements included in the individual prediction calculation. The value is presented as a specific gas emission quoted in cubic metres per tonne of coal production (M^3/t) or as a mean methane emission rate (m^3d or l/s) which is the product of specific gas emission and average daily output over a given time span.

While the basic principles of methane prediction were the same throughout, a number of countries developed alternative techniques which are described in Section 3 of this report.

1.4 PREDICTION TECHNIQUES FOR CANADA

The preceeding sections of this report have outlined the parameters utilized in methane prediction calculations. By applying existing prediction methodology, estimates have been made often within 20% of measured quantities of produced methane. These results indicate that it is already possible to predict methane emission to an acceptable level of accuracy for initial mine planning purposes.

In Section 3 of this report, procedures used in other countries are reviewed to assess their applicability to Canadian conditions. Attention is focused on developments in methane prediction techniques since 1977 using the IEA Coal Research Report, "Methane Prediction in Coal Mines" (S.J. Curl) as an original reference.

TABLE 1-1 COMPOSITION OF GAS FOR SELECTED SEAMS IN THE UNITED STATES

Seam Name	State	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}	CO_2	O_2	N_2	H_2	He
Pocahontas	W. Va.	98.73	1.27	0.0011	0.0001	-	-	-	-	-	-
Pocahontas	Va.	98.36	1.63	0.0112	0.0010	Trace	-	-	-	-	-
Pittsburgh	Pa.	88.91	0.04	-	-	-	10.97	0.04	0.05	-	ND[a]
Pittsburgh	W. Va	95.86	1.08	-	-	-	2.54	0.06	0.46	-	-
U. Kittanning	Pa.	95.47	-	-	-	-	0.10	0.47	3.97	-	-
B-Seam - Mesa Verde F.	Utah	87.84	0.05	0.0046	0.0011	-	11.99	-	0.09	-	-
Lower Hartshorne	Okl.	99.22	0.01	-	-	-	0.06	0.1	0.6	-	-
Mary Lee	Ala.	96.05	0.01	-	-	-	0.1	0.05	3.5	Trace	0.27

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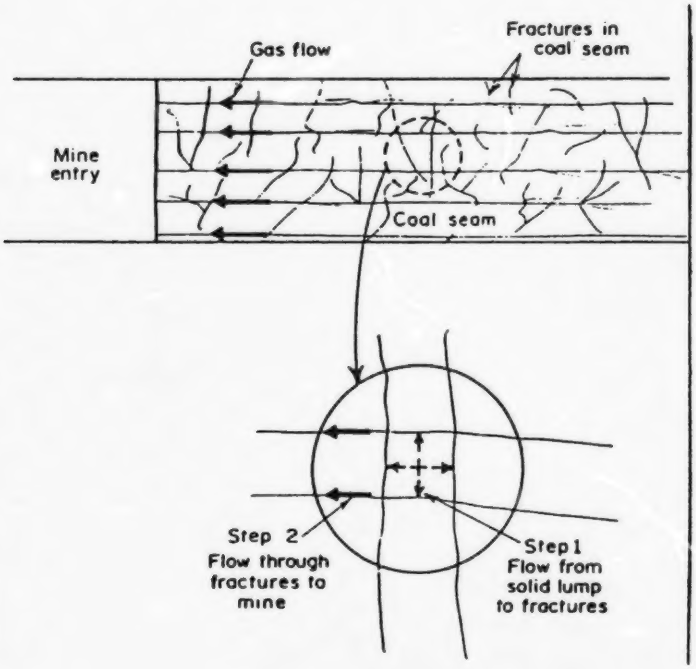
[a] Not Determined

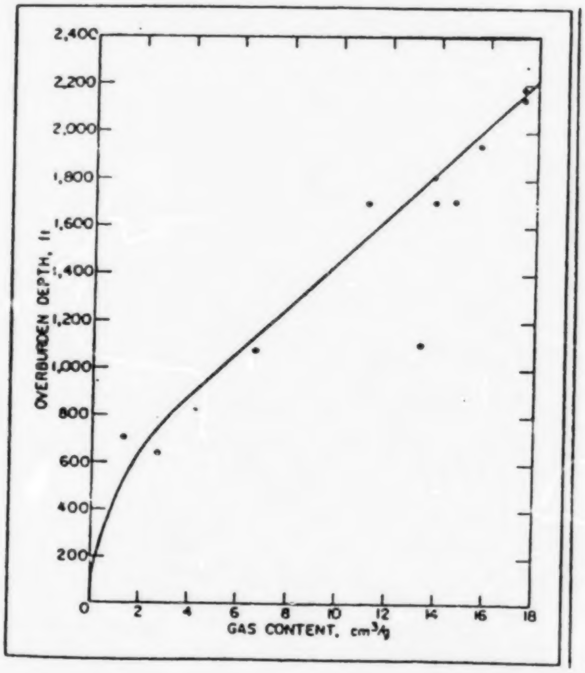
Source: Kim, 1973

FIGURE 1-1 Modes of Gas Flow Through Coal


Gas flow
Fractures in coal seam
Mine entry
Coal seam
Step 2 Flow through fractures to mine
Step 1 Flow from solid lump to fractures

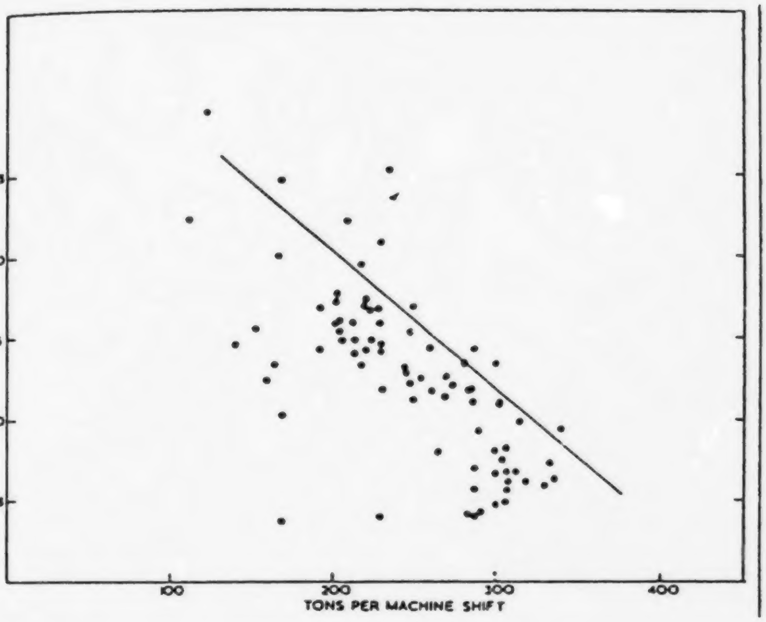
Source: Gunther, 1965

FIGURE 1-2 Gas Content Versus Depth in the Mary Lee Seam



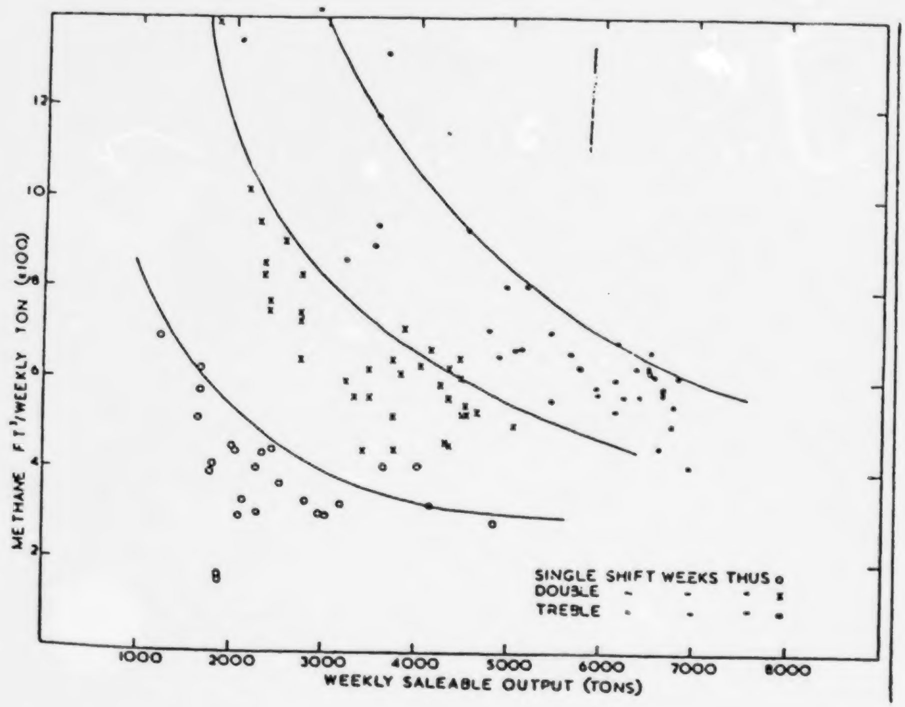
Source: Diamond, 1976

FIGURE 1-3 Variation of Gas Emission with Shift Tonnage



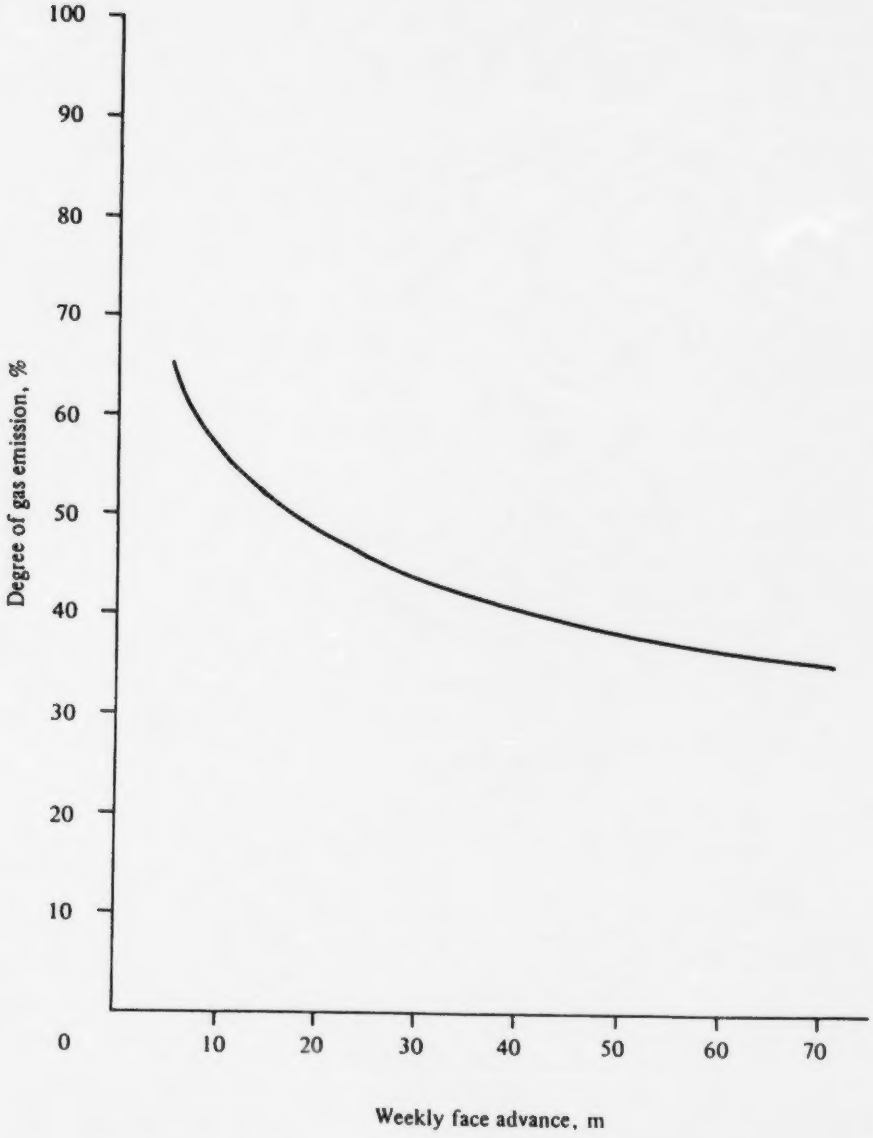
Source: Jolliffe, 1970

FIGURE 1-4 Variation of Gas Emission with Weekly Tonnage



Source: Jolliffe, 1970

FIGURE 1-5 The MRDE Curve for the Degree of Gas Emission from the Worked Seam



Source: Dunmore ,1980

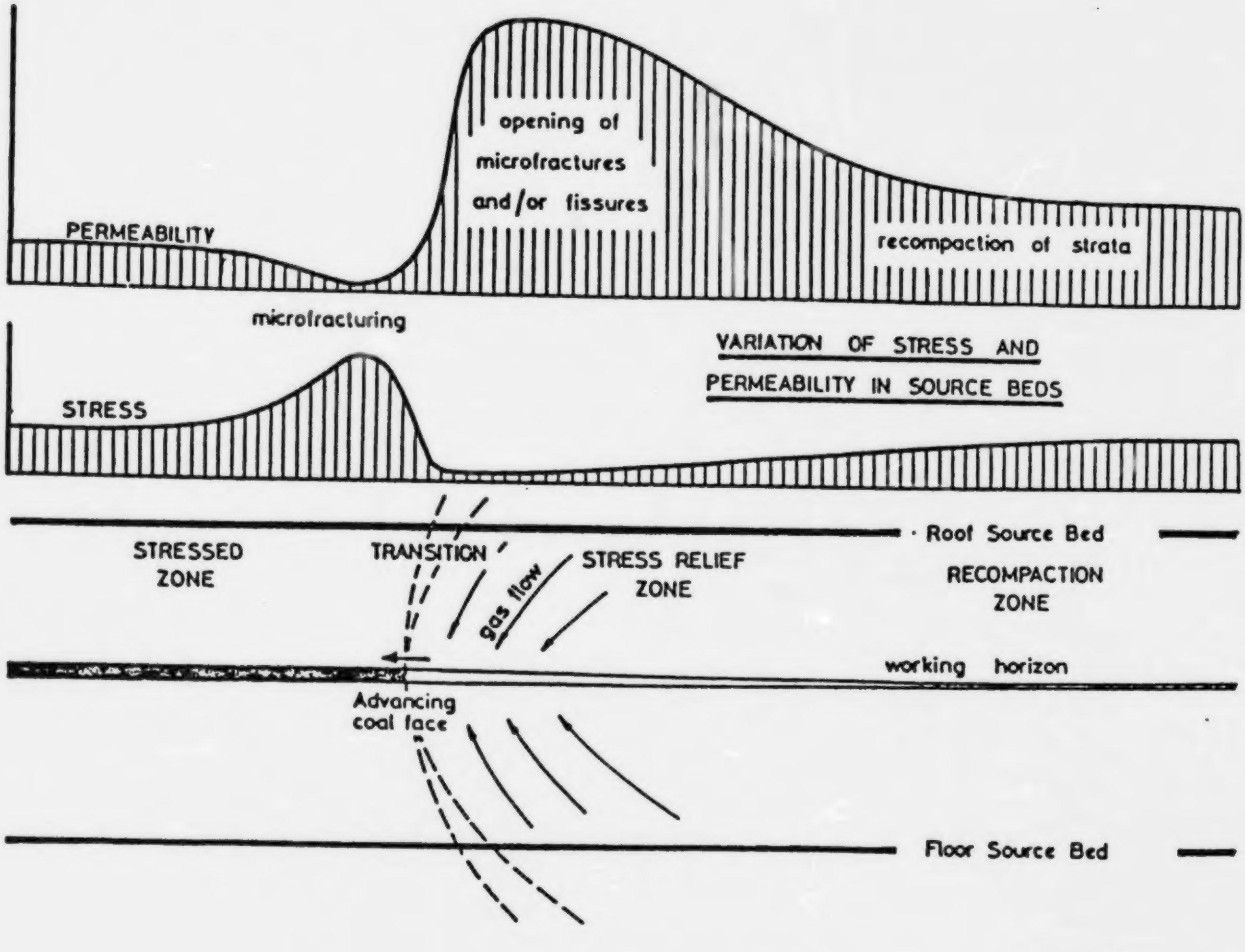
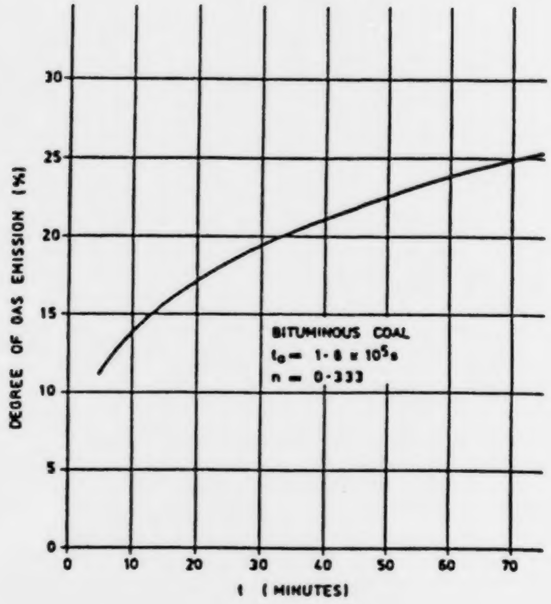


FIGURE 1-6 Variations of Stress and Permeability in Strata Above and Below an Advancing Longwall Coal Face

Source: McPherson, 1975

FIGURE 1-7 Degree of Gas Emission from Coal on a Conveyor



Source: Dunmore, 1980

COUNTRY	METHOD	HEIGHT OF ZONE OF GAS EMISSION m	DEGREE OF GAS EMISSION %
BELGIUM	INIEX	$h_R = x + d$ $h_F = -50$	$A_R = 100\%$ to $h = x$, then linear decrease to 0% at $h = x + d$ $A_F = 100\%$ to $h = -20$, then linear decrease to 0% at $h = -50$
FRANCE	GUNTHER, 1965 – 1977	$h_R = +100$ $h_F = -100$	$A_R = 100\%$ $A_F = 100 + h$
FRANCE	JEGER, 1978 on	$h_R = +170$ $h_F = -55$	$A_R = 90\%$ to $h = +30$, 80% from $h = +30$ to $+120$ then linear decrease to 0% at $h = +170$ $A_F = 90\%$ to $h = -15$, then linear decrease to 0% at $h = -55$
FRG	FLÜGGE	$h_R = 0.5\ell \tan\alpha$ $h_F = 0.5\ell \tan\alpha$ ($\alpha = 25$ gon)	• $A_R = 100 - \frac{200h}{\ell} \cot\alpha$ $A_F = 100 + \frac{200h}{\ell} \cot\alpha$ ($\alpha = 25$ gon)
FRG	SCHULTZ	$h_R = 0.5\ell$ $h_F = -20$	• $A_R = \frac{100}{\ell}\sqrt{\ell^2 - 4h^2}$ $A_F = 100\%$ to $h = -5$, then linear decrease to 0% at $h = -20$
FRG	WINTER	h_R fixed by $A_R = 10\%$ h_F fixed by $A_F = 10\%$	$A_R = 100\%$ to $h = +20$, then $A_R = 100 \exp(-\mu(h - 20))$ $A_F = 100\%$ to $h = -8$, then $A_F = 100 \exp(\mu(h + 8))$
FRG	KOPPE	$h_F = -50$ to -64 (depending on distance from face centre line, fig. 22)	$A_F = 142 + 4h + 0.027h^2$
POLAND	BARBARA MINE	$h_R = 120\ h/t$ $h_F = 120\ h/t$	$A_R = 64.7 \exp(-0.03957h/t)$ $A_F = 54.1 \exp(0.03721h/t)$
UK	NCB/MRDE	unlimited in theory, in practice $h_R = 200$ $h_F = -100$	see figure 24
USSR	LIDIN	$h_R = N.t.\ (1.2 + \cos\theta)$ $h_F = N.t.\ (1.2 - \cos\theta)$	$A_R = 100\ (1 - h/h_R)$ $A_F = 100\ (1 - h/h_F)$

Nomenclature

All methods: –

h_R = maximum height of emission zone in the roof, m.

h_F = maximum depth of emission zone in the floor, m.

h = height or depth from worked seam, m.

A_R = degree of gas emission in the roof, %.

A_F = degree of gas emission in the floor, %.

Belgium: –

x = height in roof of 100% gas emission, m.

d = height in roof, above x, in which gas emission decreases to 0%, m.

FRG: –

ℓ = face length, m.

α = angle of prism in Flügge's method, gon or degrees.

μ = attenuation co-efficient for Winter's method.

USSR & Poland: –

N = mining factor, e.g. $N = 60$ for full caving, $N = 45$ for stowing.

t = extracted seam thickness, m.

θ = dip of strata, gon or degrees.

FIGURE 1-8 Definitions of the Zone and Degree of Gas Emission for Prediction Methods

Source: Curl, 1978

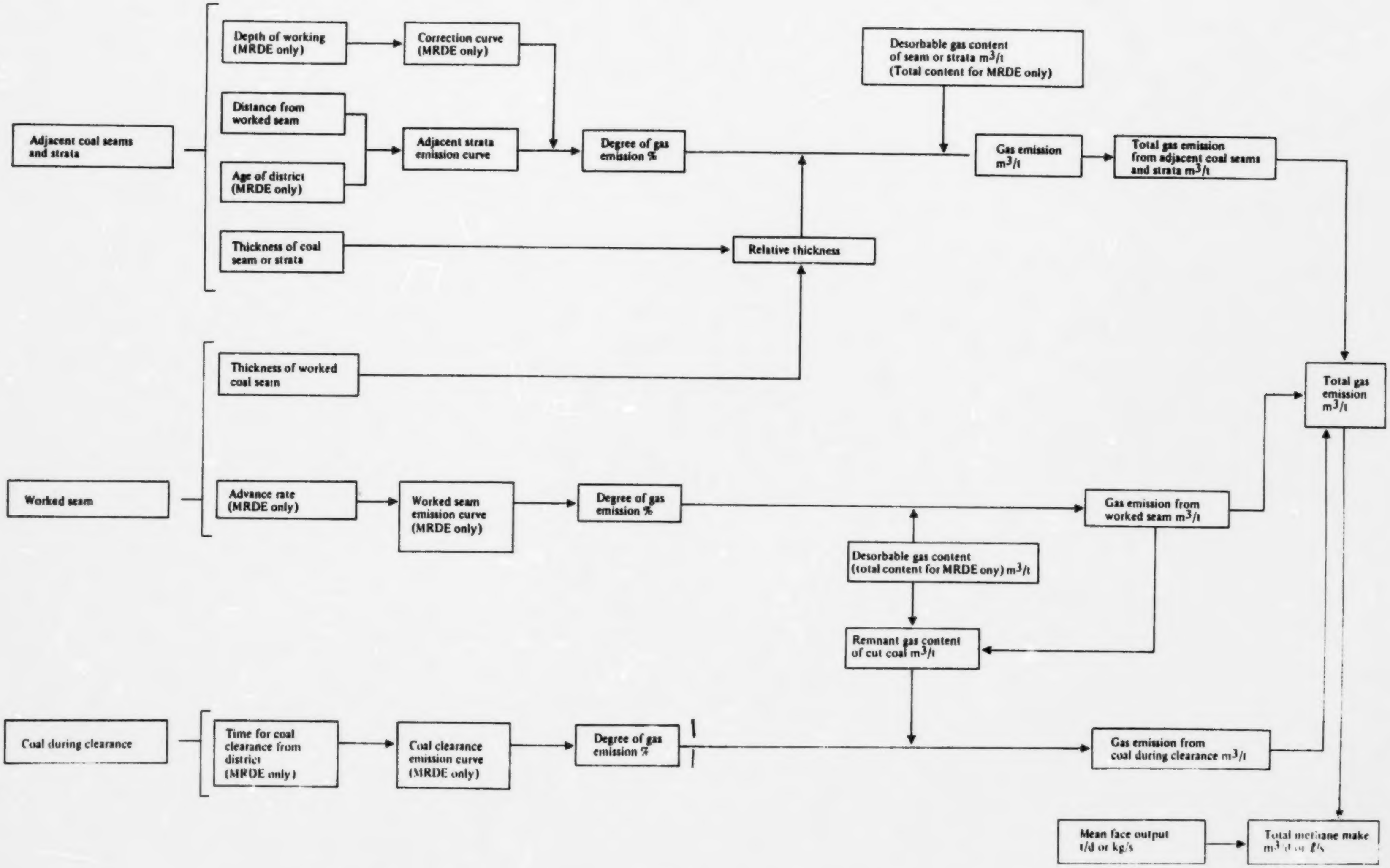

Adjacent coal seams and strata
Depth of working (MRDE only)
Correction curve (MRDE only)
Distance from worked seam
Age of district (MRDE only)
Adjacent strata emission curve
Degree of gas emission %
Thickness of coal seam or strata
Relative thickness
Desorbable gas content of seam or strata m3/t (Total content for MRDE only)
Gas emission m3/t
Total gas emission from adjacent coal seams and strata m3/t
Worked seam
Thickness of worked coal seam
Advance rate (MRDE only)
Worked seam emission curve (MRDE only)
Degree of gas emission %
Gas emission from worked seam m3/t
Desorbable gas content (total content for MRDE ony) m3/t
Remnant gas content of cut coal m3/t
Total gas emission m3/t
Coal during clearance
Time for coal clearance from district (MRDE only)
Coal clearance emission curve (MRDE only)
Degree of gas emission %
Gas emission from coal during clearance m3/t
Mean face output t/d or kg/s
Total methane make m3/d or ℓ/s

FIGURE 1-9 Flow Chart of European Prediction Methods

Source: Curl, 1978

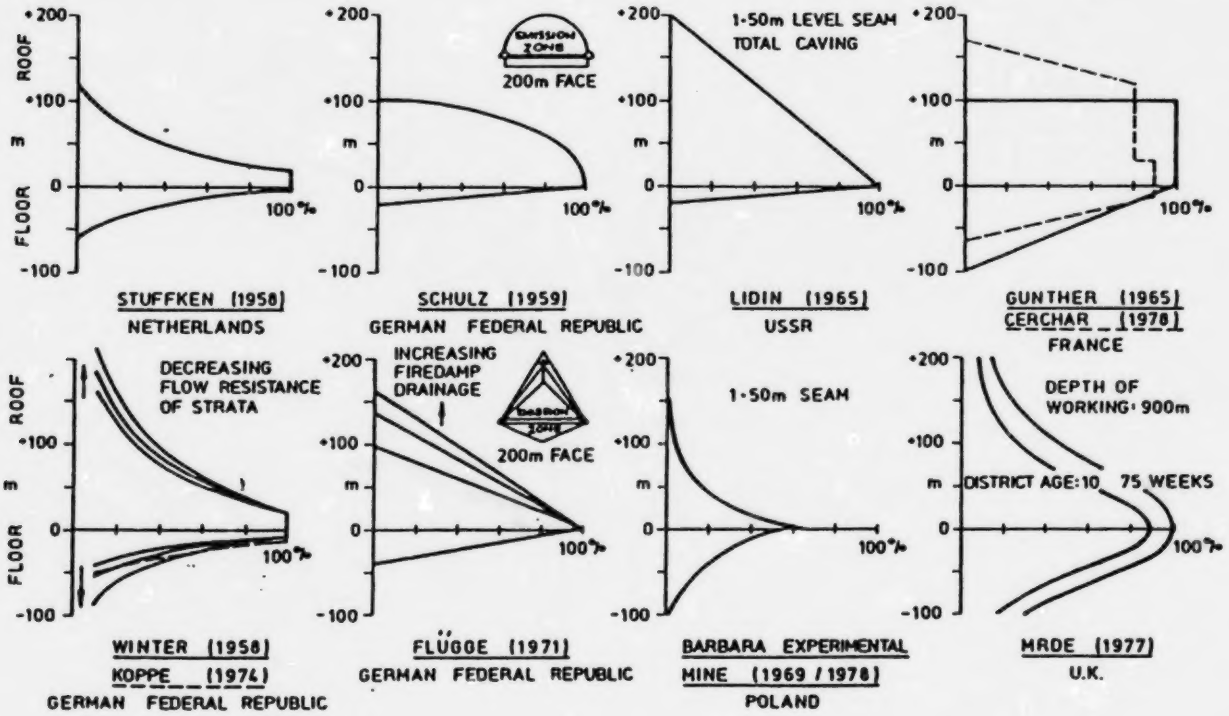


FIGURE 1-10 Adjacent Seam Gas Emission (%) as a Function of Distance from the Worked Seam, according to Various Authorities

Source: Dunmore, 1980

SECTION 2

CANADIAN OPERATIONS AND CONDITIONS

SECTION 2

CANADIAN OPERATIONS AND CONDITIONS

2.1 INTRODUCTION

There are active underground coal mines in three Canadian Provinces: Alberta, British Columbia and Nova Scotia. The scale ranges in size from very small operations to major undersea mines. Mining methods used include room-and-pillar, hydraulic, advance longwall and retreat longwall.

Geographically and geologically the mines fall naturally into the two groupings of Eastern Canada and Western Canada and it is in this context that they are reviewed.

2.2 WESTERN CANADIAN OPERATIONS

2.2.1 Smoky River Coal Limited

Room-and pillar mining is used in No. 4 Seam at mine No. 9B. A five entry system is employed with the entries extracting the top 3 m of the 6 m thick seam. Some floor coal is extracted during depillaring. Annual production averages 1 Mt of raw coal.

A second adit mine, No. 9G, has been developed in the same seam but no further production is currently planned from this mine.

2.2.2 Westar Mining Limited

Underground coal mining is applied at Sparwood where Westar Mining Ltd. has operated two underground mines in No. 10 Seam utilizing both room-and-pillar and hydraulic mining. These mines are referred to us Balmer North and Balmer South respectively.

Balmer North is a single section room-and-pillar mine. Development is by two and three entry roadways and floor coal is taken on the retreat. The mine is currently retreating and no further development is planned.

Balmer South was a hydraulic mine accessed by both rock tunnels and in-seam entries. The coal was extracted by hydraulic methods. Production from this mine ceased in 1985 and it is now sealed off.

2.2.3 Other Western Canadian Underground Coal Mines

Luscar Sterco: underground coal mine on the Coal Valley property has been abandoned. Some feasibility work has been done in relation to a future underground mine.

Cardinal River Coal Ltd.: this company was developing an underground hydraulic mine on its property near Hinton, Alberta. This development has been abandoned and the mine entries have been sealed.

Wolf Mountain Coal: this company is operating a room-and-pillar mine near Nanaimo, British Columbia. Currently the mine is in a non-productive phase.

Quintette Coal Ltd.: this company is currently conducting a feasibility study for underground coal mining on their Quintette property in N.E. British Columbia.

Underground coal mining in Western Canada is decreasing. Existing operations are not developing and the only potential for a new underground mine would appear to be at Quintette. However, a number of companies have studies in place for hydraulic mining. Ventilation techniques for this mining method are still in a relatively early stage of development and the impact that methane emission has on the development of these systems requires a thorough evaluation. Given the difficulty of simply developing an adequate ventilation system for this mining method, the assessment of the validity of appropriate methane prediction techniques for this mining method requires much exhaustive research and testing far beyond the scope of the current review.

2.3 EASTERN CANADIAN OPERATIONS

2.3.1 Cape Breton Development Corporation (CBDC)

CBDC is the major producer of coal from underground mines in Canada. Existing operations consist of two undersea mines in the Sydney Coalfield and there are plans in place for two new mines.

Coal production comes from four coal seams mined by both advance and retreat mechanized longwall systems. The operational mines are the Prince Mine and the Lingan Mine.

> **The Prince Mine** is an undersea drift mine accessed by slopes, working the Hub Seam by short longwall retreat faces. Annual production is approximately 0.7 Mt product coal. The faces are equipped with double ended shearers, armoured flexible conveyors and powered supports. Total mine ventilation is 76 m^3/s. The distance from the surface to the projected most in-bye working point is approximately 7 km.
>
> **The Lingan Mine** is an undersea drift mine, accessed by five slopes, working the Harbour Seam by longwall advancing faces. Annual production is approximately 1.2 Mt product coal. The faces are equipped with double ended shearers, armoured flexible conveyors and powered supports. Total mine ventilation is 205 m^3/s. The distance from the surface to the projected most in-bye working point is approximately 6 km.

Mines currently planned for development are the Lingan-Phalen Mine and the Donkin Mine.

The Lingan - Phalen Mine will be an undersea drift mine with access by three slopes to work the **Phalen Seam** by longwall retreat faces. Annual production is projected at 2 Mt. product coal. Faces will be equipped with double ended shearers, armoured flexible conveyors and powered supports. The distance from the surface to the projected extent of the workings is about 8 km.

The Donkin Mine will be an undersea drift mine, accessed by two slopes, working the Harbour, Hub and Lloyd Cove Seams by longwall retreat faces. Annual production is projected at 4 Mt. Faces will be equipped with double ended shearers, armoured flexible conveyors and powered supports. The distance from the surface to the projected extent of the workings is 12 km.

Planning within CBDC is for a significant increase in productive capacity within the next decade. This planning incorporates high-production longwall faces in mines with considerable lateral extent. Under these circumstances, accurate methane prediction will be essential.

2.3.2 Other Nova Scotian Coal Mines

The Evans Mine is a drift mine with access by slopes and worked by room-and-pillar method using scrapers for coal production. Annual production is approximately 50,000 t of product. The distance from the surface to the most distant working place is about 1.5 km.

2.4. SYDNEY COALFIELD

2.4.1. General

Underground coal production in Canada is, essentially, centered on the Sydney Coalfield. This production is planned to expand and new production will come from highly mechanized longwall faces, where potential methane problems will exist. A proven prediction technique for gas emission will substantially assist ventilation planning in averting these potential hazards. To derive an appropriate prediction technique requires basic knowledge of the geological elements which have a significant impact on methane emission.

2.4.2. Geological Setting

The Sydney Coalfield is located on the northeastern edge of Cape Breton Island in Nova Scotia. A marine transgression has submerged most of the original intermontaine basin leaving only a small landward expression. The extent of the submarine portion of the coalfield is not known but appears to be considerable. To the west and south, pre-Carboniferous rocks are present in highlands which probably represent the old positive source area of the basin. In the southwest, the basin has been faulted against Precambrian rocks with erosional remnants of Mississippian Hortan-Windsor Group in unconformable contact with the overlying Pennsylvanian sediments.

The Sydney Coalfield is considered to be a limnic depositional basin having no evidence of marine incursions during deposition. Clastic sedimentation in the gently subsiding basin was largely controlled by the river channels, levees and interdistributory troughs. It is apparent that the sediment supply was always sufficient to maintain the level of the flood plain above sea level. Deposition of the coal and the associated fluvio-lacustrine sediments took place in a flood plain or valley floor environment.

This type of environment allows for the development of thick, laterally extensive seams not withstanding associated rapid lateral variations in interseam lithology. The coal seams themselves are excellent marker horizons.

The low gradient of this depositional environment permitted the development of an extensive meandering river system with channel anastomosis.

All the sedimentary strata in the area are assigned to the Pennsylvanian Morien Series of Late Westphalian C to possibly Stephanian age. The landward expression of the Morien Series attains a maximum stratigraphic thickness of 1965 metres in the Glace Bay area and is transgressive to the northwest where it onlaps older strata.

The Morien Series can be subdivided into two major lithologic units. Below the Tracy seam, the lower half of the series is generally non-coalbearing and consists of a monotonous sequence of grey-brown sandstones colloquially known as the Millstone Grit. Three very thin coal seams occur near the top of this setion. A transitional zone between the two units is present between the Tracy and Phalen seams. The lithology grades into the predominantly sandy shales and siltstones of the productive coal sequence.

The landward expression of the coal measures is approximately 50 kilometres long, measured in a southeast to northwest direction, and attains a maximum width of 30.5 kilometres. The highest strata exposed on land occur just above the Point Aconi seam.

Above the Phalen seam, the section becomes increasingly fine-grained reaching a maximum silty shale content of 70% to 80% above the Harbour seam. In the off-shore region the section becomes essentially 100% silty claystone above the Murphy seam.

The specific interseam lithology varies considerably though the shale/sand ratio is remarkably uniform over the entire coalfield.

The tectonic develoment of the Sydney Coalfield has been very gentle with no serious structural problems occuring in the working areas. Only gentle folds are present which fan out seaward and trend in a general northeasterly direction. Minor thrust faulting is present and probably occurred as a response to orogenic movements during the Permo-Triassic.

Figure 2-1 illustrates the geological structure of the Sydney Coalfield.

2.4.3 Coal Seam Stratigraphy

Consistant with the geological environment, the coal seams appear to have great lateral continuity and relatively consistent thickness. The seams may be readily correlated between widely-spaced data points.

Only four seams are believed to reach a mineable thickness and their development has been traced across the region. These are listed in Table 2-1 and described in the following paragraphs.

> **The Phalen Seam,** the lowest of the four under consideration, reaches a maximum thickness of 2.7 metres and averages 2.2 metres. The seam contains four characteristic bone bands lettered A to D from the base up in the old Lingan Mine area. The lowermost of these, A, is only present to the west in the New Waterford area. Westward from this area all four bands pass into thick shale partings leaving five unmineable benches of coal. Within the resource block area of No. 26 Colliery, band A is not present. Bands B and C occur as a thin bone and a durain band, respectively. Band D develops into a stone parting. Figure 2-2 is a typical seam section from the Lingan Phalen area. Toward the west the parting thickens rapidly, attaining 0.3 metres in the vicinity of the old Lingan Mine. The partings occur as a result of fluvial deposition of silt and clay within the peat bog.
>
> **The Harbour Seam** is one of the most consistent and best developed seams in the Sydney Coalfield. Shale partings are rare. Within the existing workings of No. 26 Colliery the seam maintains an average thickness of 2.0 to 2.25 metres. Isolated areas with thicknesses as high as 2.5 and as low as 1.8 metres have been recorded. In the Donkin Block thicknesses range from 2.8 to 3.6 metres. Changes in

thickness appear to be fairly minor but have an irregular and variable distribution.

Four bone bands with a characteristic petrographic composition are present and can be identified over the entire coalfield. The benches between these bands are not uniformly developed, with the result that sections of uniform thickness may not represent the same interval of peat deposition.

Within the No. 26 Colliery area, the lowermost bone bands (A and B) are significant since they thicken to partings in excess of 0.6 metres. The lower two benches disappear into the pavement.

The Hub Seam appears to be split into three benches with only one being considered thick enough to mine. The equivalent of these three benches appears to exist in the Prince Mine area (Figure 2-3). Analysis of the off-shore drill holes in the Donkin-Morien area illustrates how variation in rock band thickness influences mining section. Within the reserve of No. 26 Colliery the thickness of this seam appears to be less than 1.6 metres. However, in the Donkin area the mineable coal, representing a portion of the seam, achieves a thickness of at least 2.7 metres.

Little data is available on the development of the **Lloyd Cove Seam.** In the eastern portion of No. 26 Colliery the seam has deteriorated to the point of being almost non-existent. In the Donkin reserve block, estimates of thickness vary from 1.0 to 3.0 metres. The seam appears to occur in two benches with a rock split which diminishes towards the west.

2.4.4 Roof and Floor Strata

In general, the roof of the **Harbour Seam** throughout the present mine workings is composed of mudstone or shale, which may be silty in part. Siltstone and sandstone, both as discrete units or as interbedded and graditional units, are also present.

A potentially significant factor in the Harbour Seam is the effect of paleosandstone river channels. These have been investigated in considerable detail by CBDC geological staff (Forgeron, 1980).

Linear sandstone bodies, generally trending in a northeasterly direction, exist in the roof strata of the Harbour seam and it is CBDC's contention that they represent river channels which traversed the region of coal deposition. They are similar in form to "washouts" observed in coal seams elsewhere, in that they cut into the upper part of the seam in some localities. Figure 2-4 is a schematic illustration of projected areas of sandstone roof throughout the coalfield (after Forgeron, 1980).

The sandstones are fine to medium-grained, quartz-lithic, and generally massive. Mica is present but not to the degree where bedding plane partings have developed.

The floor of the Harbour seam is composed of hard, dark grey shale, which exhibits fissility in some areas.

The roof strata of the **Phalen seam** are essentially similar to those of the Harbour seam. In the No. 26 Colliery, resource area borehole information showed shale overlain by sandstone. The Phalen seam floor is recorded as being a hard shaley siltstone, carbonaceous in part.

Examination of cores containing gas or hydrocarbons recovered from the off-shore holes indicates that, in the fine grained sandstones, the effective porosity has been almost eliminated due to compaction and cementation. In that the mudstones and shales are finer grained and equally compacted, it can be expected that a similar condition will prevail. Some minor influence of water could be expected in association with the sandstone channel fills referred to above.

Like the Harbour Seam, sandstone channels are known to occur in the roof of the **Hub Seam.** A figure illustrating the occurence of these features and a section illustrating lithologies of seam roof and floor strata in the Prince Mine area are shown on Figure 2-5.

In general, lithologies of the roof and floor strata of the **Lloyd Cove Seam** are consistant with those found adjacent to the underlying Hub Seam. There are, however, no significant reported occurences of channel sandstones occurring within the roof of this seams observed features. Nevertheless, it is apparent that the most obvious cleat orientation has been determined and it is assumed that this represents the direction of highest fracture permeability within the Harbour Seam. The limited data available for the Hub Seam suggests that an equivalent condition will apply. It is anticipated through consideration of the mechanism for formation of joints and cleats that the same conditon also exists in the other potentially minable seams.

2.4.5 Porosity and Permeability

Although they are by no means the only geological factors of significance in evaluating the potential for methane emission, porosity and permeability data are probably the most important information. Data relating to the geological conditions of fracture porosity and permeability of the coal and also for the roof and floor strata are required to predict methane emissions. There is no data available for the Sydney Coalfield concerning these parameters.

Porosity and permeability data obtained from intact samples from the roof, floor and seam lithologies can also be of assistance. No such data exists for the coal seams within the Sydney Coalfield, and only a limited amount of data is available for the roof and floor rocks. This data is derived from laboratory tested core samples and has not been related to in-situ conditions.

Appendix A includes the available porosity and permeability data for the Sydney Coalfield.

TABLE 2-1 SYDNEY COALFIELD SEAM SEQUENCE

Seam	Coal Interval Thickness (m)	Interseam Thickness (m)
Point Aconi	1.0 - 2.0	
		70 - 90
Lloyd Cove	10. - 3.0	
		60 - 70
Hub Zone *(1)	3.0 - 13.0	
		90 - 110
Harbour (2)	2.0 - 4.5	
		60 - 80
Bouthillier	0.5 - 1.0	
		20 - 40
Back Pit	0.5 - 1.0	
		30 - 35
Phalen (3)	0.5 - 2.0	
		40 - 60
Emery	0.5 - 1.5	
		130
Gardiner	0.5 1.5	
		330
Mullins	1.0 - 2.0	
		175
Tracey	1.0 - 2.0	

(After Haites, 1951; Forgeron, 1980; including Donkin-Morien data).

* May include up to 10 m of major rock partings

(1) Prince Mine and Donkin Morien Project (long term)
(2) Lingan and #26 Mines; Glace Bay and Donkin Morien Projects
(3) Lingan-Phalen and Glace Bay Projects

Source: Forgeron, 1980

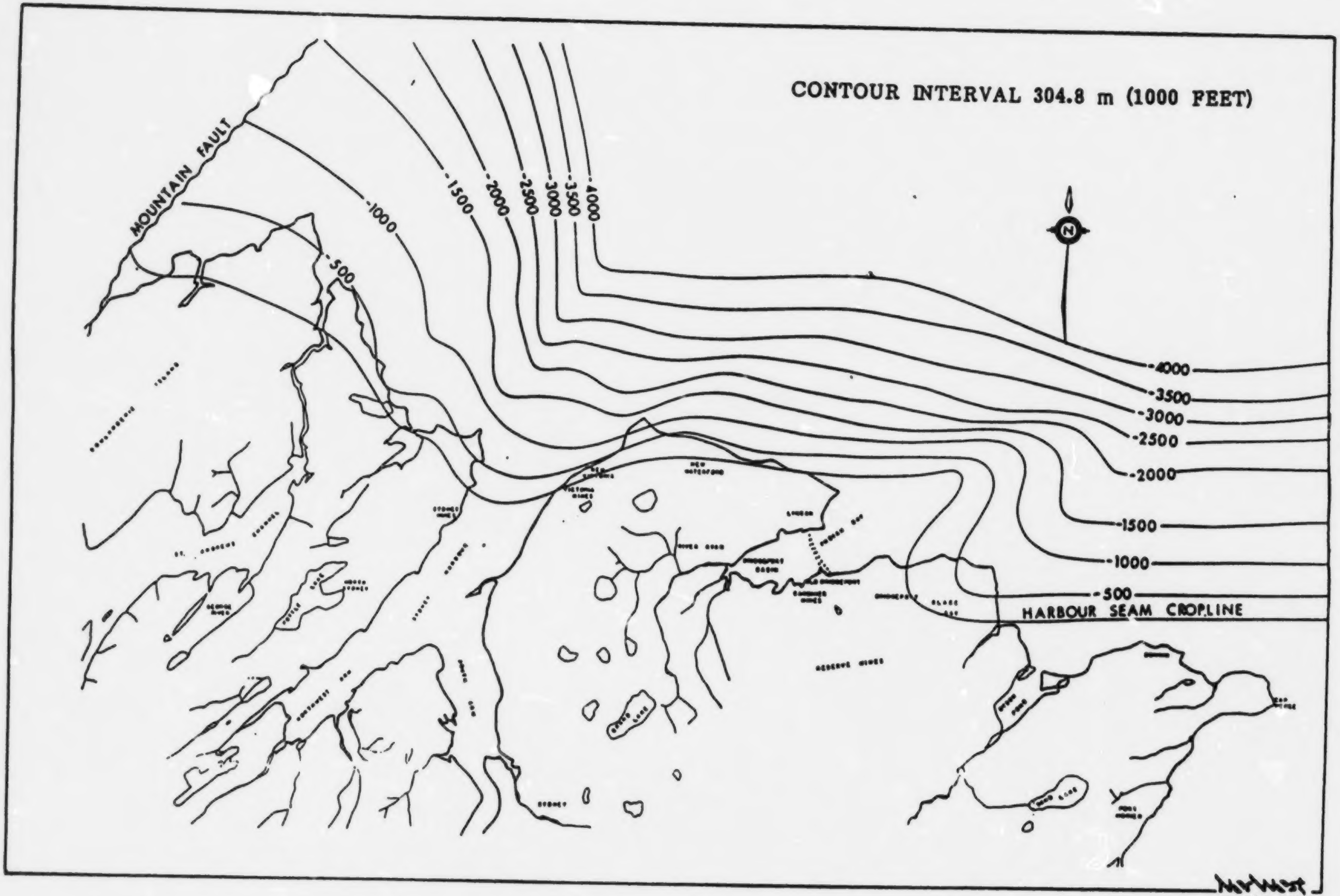
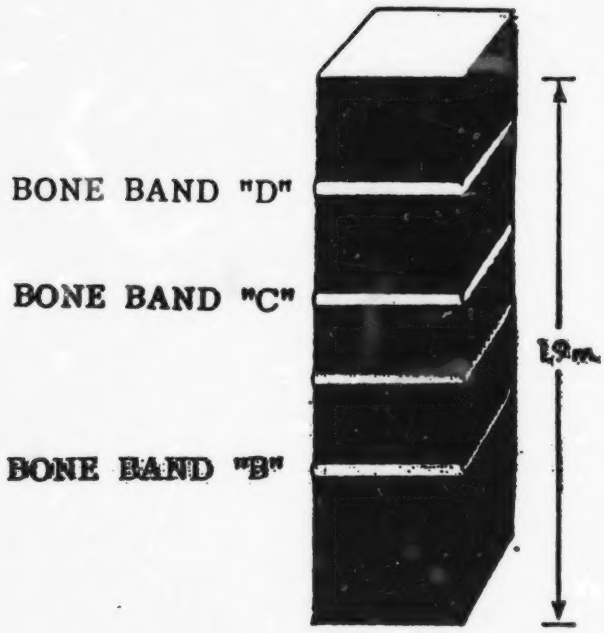


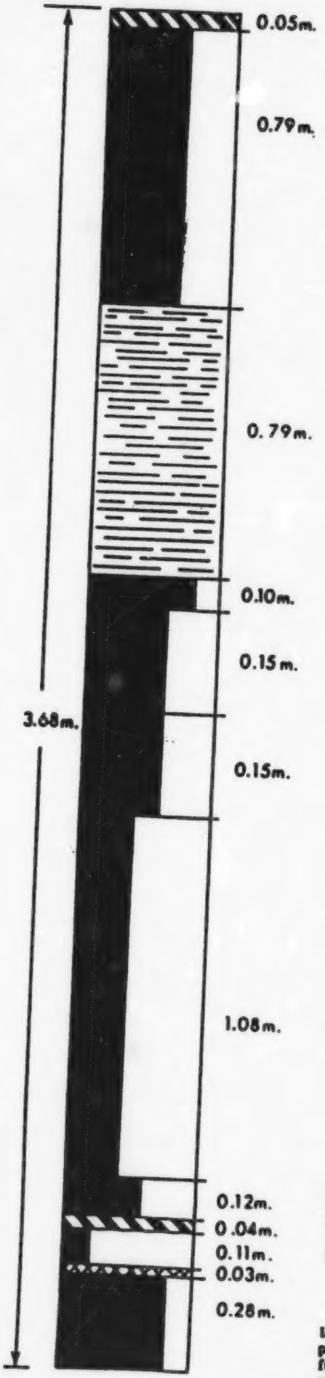
FIGURE 2-1 Structure Contours, Base of Harbour Seam

HARBOUR SEAM IN THE VICINITY
OF THE CENTRE OF #26 COLLIERY



BAND "A" IS NOT PRESENT IN THIS
PART OF THE COLLIERY

FIGURE 2-4A TYPICAL SECTION OF HARBOUR SEAM



Intermediate to bright banded coal; locally, contains dull bands of durain; well developed cleat; coated with scales of transparent carbonate; fusain lenses (up to 0.02' thick) common throughout section.

Intermediate to bright banded coal; minor ankerite along cleat; contains a few streaks of pyrite.

Intermediate to bright banded coal; highly broken in core box; high in fusain.

Intermediate to bright banded coal; minor ankerite along cleat; slickensided joint dipping at an angle of 70° observed; 1/8" thick durain band in top 1"; ½" durain band in lower 1".

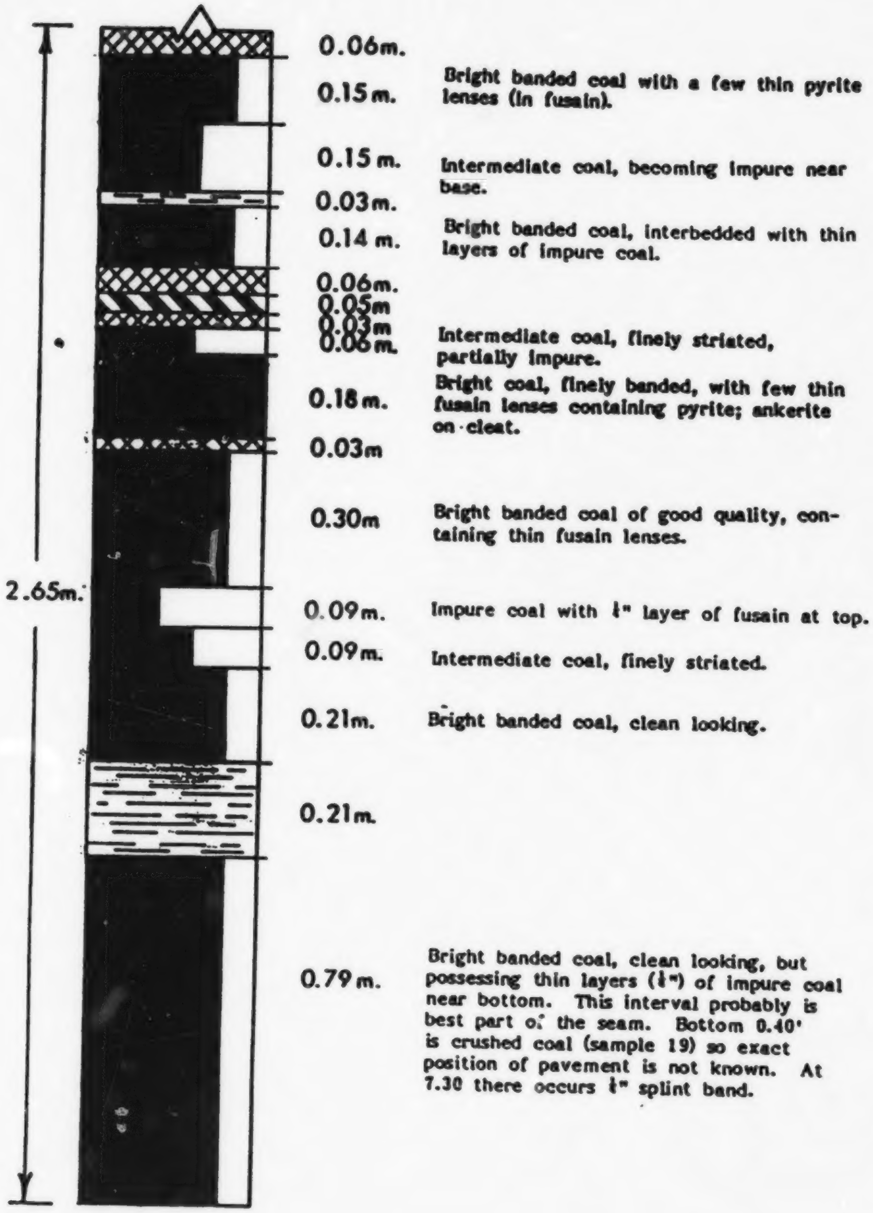
Bright banded coal; thin fusain lenses present throughout section; carbonate along cleat, locally contains pyrite.

Intermediate to bright banded coal, quite high in fusain, streaks of pyrite along cleat, ankerite along cleat.

Splint, hard, high in ash and pyrite.

Intermediate to bright banded coal, pyrite common along bedding; some fusain containing pyrite, top 2" mostly dull.

FIGURE 2-2 Typical Section for the Phalen Seam in the Lingan Phalen Area



0.15 m. Bright banded coal with a few thin pyrite lenses (in fusain).

0.15 m. Intermediate coal, becoming impure near base.

0.03 m.

0.14 m. Bright banded coal, interbedded with thin layers of impure coal.

0.06 m. Intermediate coal, finely striated, partially impure.

0.18 m. Bright coal, finely banded, with few thin fusain lenses containing pyrite; ankerite on cleat.

0.30m Bright banded coal of good quality, containing thin fusain lenses.

0.09 m. Impure coal with ⅛" layer of fusain at top.

0.09 m. Intermediate coal, finely striated.

0.21m. Bright banded coal, clean looking.

0.79 m. Bright banded coal, clean looking, but possessing thin layers (⅛") of impure coal near bottom. This interval probably is best part of the seam. Bottom 0.40' is crushed coal (sample 19) so exact position of pavement is not known. At 7.30 there occurs ⅛" splint band.

FIGURE 2-3 Typical Section for the Hub Seam in the Prince Mine

Source: Forgeron, 1980

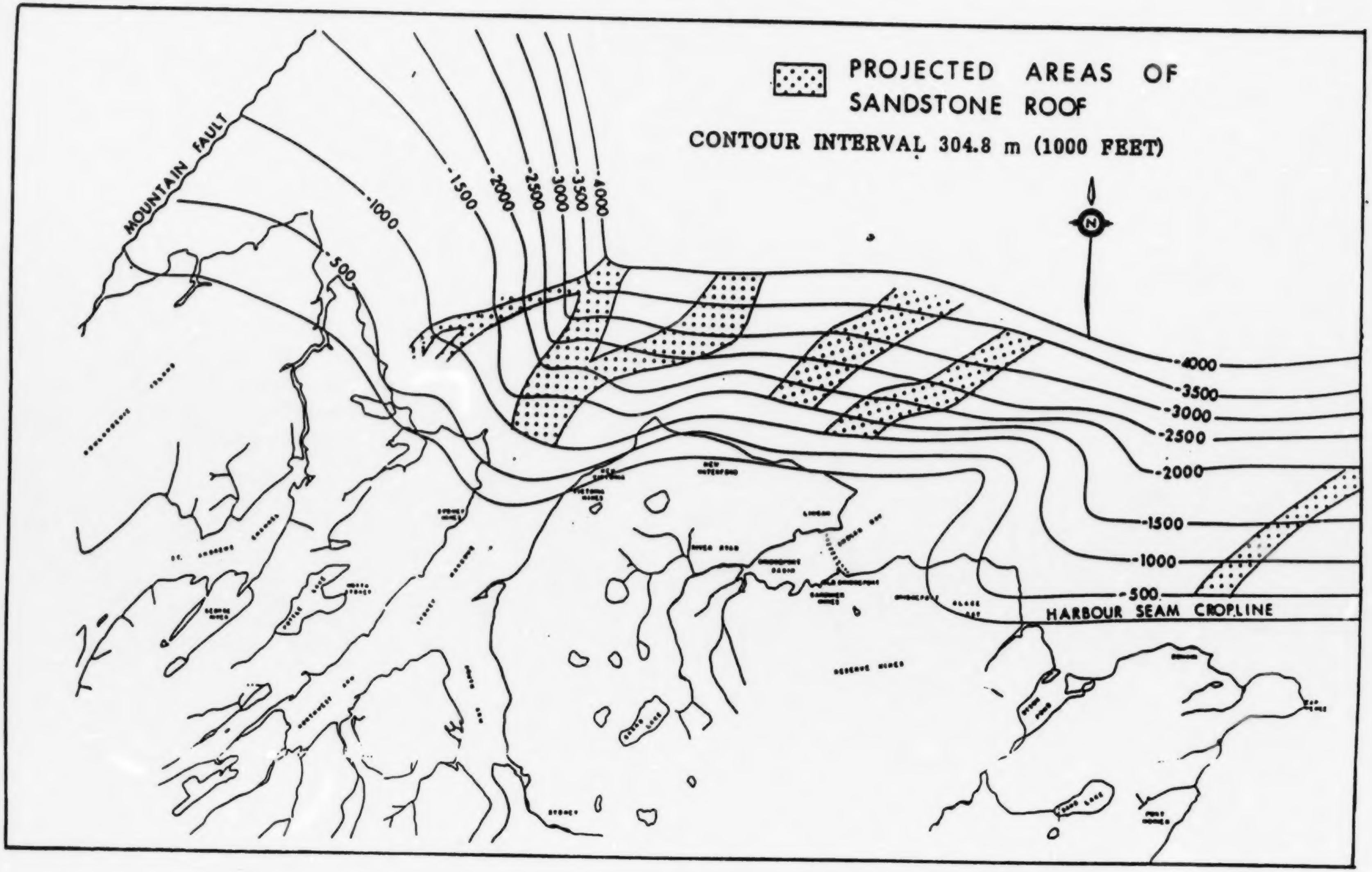
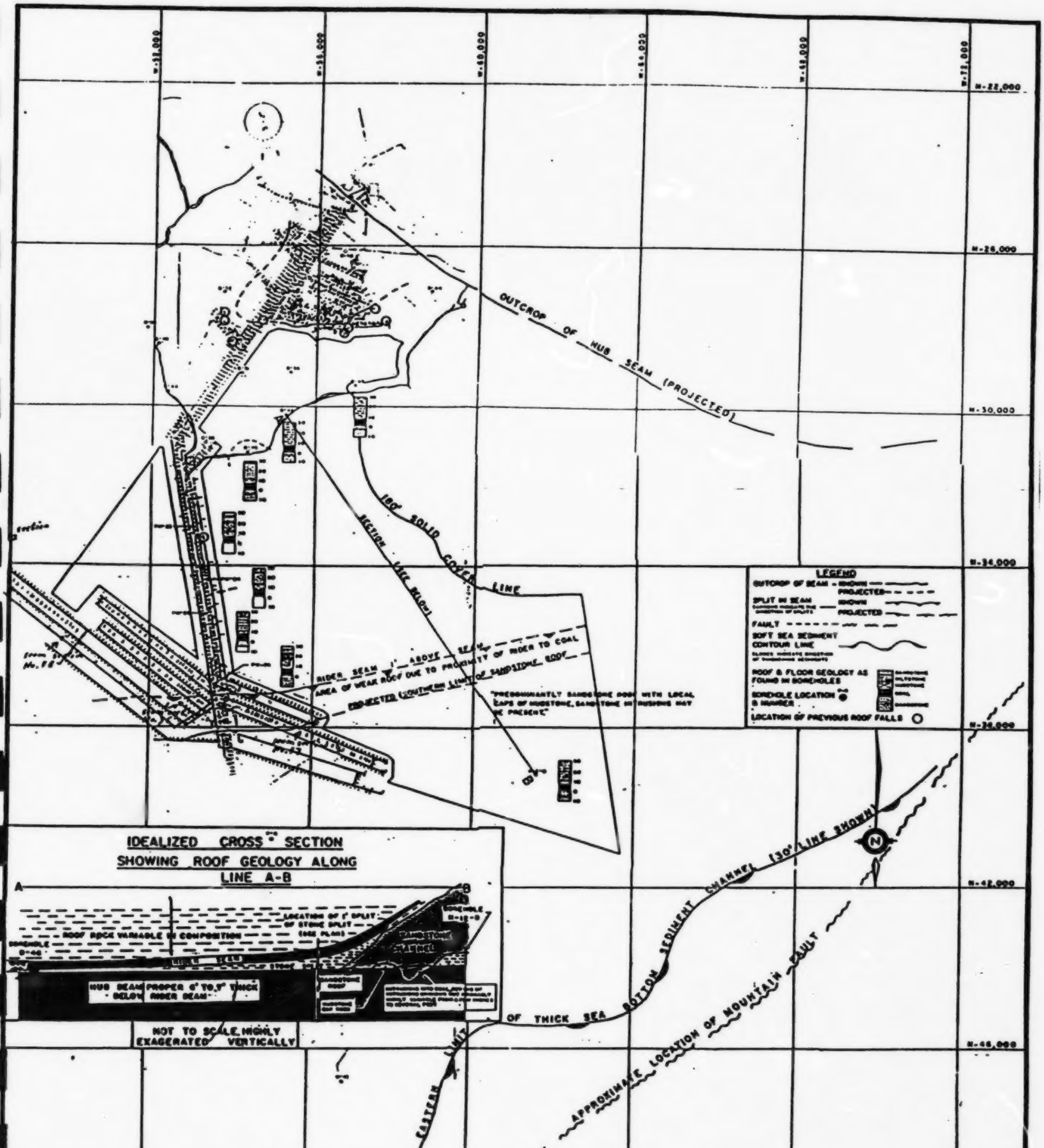


FIGURE 2-4 Harbour Seam Structure

FIGURE 2-5 Prince Mine Geology of Resource Block

Source: Forgeron, 1980


N-22,000
N-26,000
N-30,000
N-34,000
N-38,000
N-42,000
N-46,000
OUTCROP OF HUB SEAM (PROJECTED)
180' SOLID COVER LINE
SECTION LINE BELOW
RIDER SEAM 1' ABOVE SEAM
AREA OF WEAK ROOF DUE TO PROXIMITY OF RIDER TO COAL
PROJECTED SOUTHERN LIMIT OF SANDSTONE ROOF
"PREDOMINANTLY SANDSTONE ROOF WITH LOCAL LAPS OF MUDSTONE, SANDSTONE INTRUSIONS MAY BE PRESENT"
LEGEND
OUTCROP OF SEAM - SHOWN
PROJECTED
SPLIT IN SEAM
SHOWN
PROJECTED
FAULT
SOFT SEA SEDIMENT CONTOUR LINE
ROOF & FLOOR GEOLOGY AS FOUND IN BOREHOLES
BOREHOLE LOCATION & NUMBER
LOCATION OF PREVIOUS ROOF FALLS
IDEALIZED CROSS SECTION SHOWING ROOF GEOLOGY ALONG LINE A-B
A
B
ROOF ROCK VARIABLE IN COMPOSITION
SANDSTONE CHANNEL
HUB SEAM PROPER 6' TO 7' THICK BELOW RIDER SEAM
NOT TO SCALE, HIGHLY EXAGERATED VERTICALLY
EASTERN LIMIT OF THICK SEA BOTTOM SEDIMENT CHANNEL (30' LINE SHOWN)
APPROXIMATE LOCATION OF MOUNTAIN FAULT
N

SECTION 3

METHANE PREDICTION TECHNIQUES

SECTION 3

METHANE PREDICTION TECHNIQUES

3.1 INTRODUCTION

The oldest method of predicting methane emission is to base forecasts on past records of gas flow in the ventilating air current. This method is, however, only as reliable as the accumulated data. Reliable forecasting from the data base occurs when the working method and mining parameters remain unchanged. Variations in geometry and method of working can significantly alter the emission pattern, which would then result in considerable deviation from the predicted gas quantities.

European investigators use empirical methods of methane emission prediction. The data base required for these methods is outlined in Section 1.3 of this report. The empirical method is dependent upon a reliable data base. Variations in the methods of obtaining this information and the stratum investigated, are the major differences between the approach taken by individual investigators.

Two methods of gas content measurement are used; direct and indirect. Direct methods involve sampling previously undisturbed coal, with the minimum of gas loss, and measuring the gas released from the sample. An estimate of the quantity of gas lost prior to sampling is included in the emission calculation. Indirect methods involve the measurements of gas pressure from which a gas content is deduced using a sorption isotherm.

Investigators in the USA are developing computer prediction methods based on the application of the mathematical relationship between all variables affecting methane flow. This approach can be considered to be a theoretical one since methane testing is only required to check the accuracy of prediction and is not required to establish the numerical values to allow prediction to be performed as in the European method. The accuracy of the computer prediction will be tested at specific trial sites.

3.2 STATUS OF METHANE PREDICTION IN 1977

3.2.1 United Kingdom

The Mining Research and Development Establishment (MRDE) of the National Coal Board is developing a methane prediction technique based on Airey's theory of gas emission from coal. The method has the uniqueness of including a time dimension. The age and advance rate of the working district are required for the calculation of degree of gas emission from the individual seam sources. Only coal seams are considered as potential sources of methane, but gas found in other strata can be included in the calculations.

The system is empirical and requires emission data:

- for the worked seam,
- for adjacent seams,
- for broken coal in transit.

Programs are being developed to further enhance the accuracy of the emission data.

The greatest proportion of the gas emitted into the working district is considered to come from adjacent coal seams. To calculate this MRDE has adopted a non-symmetrical gas emission distribution model which is based on Airey's work related to the distribution of stress in the strata around longwall workings. Also, this method allows the remnant methane content in adjacent sources to be calculated at any time during the mining of the worked seam. If an adjacent seam is subsequently worked, the anticipated methane make from the surrounding, partially degassed seams can then be predicted.

The method takes into account methane drainage, methane peaks, 5-day working, variable rates of advance and holidays by adopting a concept coefficient of irregularity. This is used to calculate the ventilation requirements of the working district. Programs are in place to refine this peak factor.

Results are presented either graphically or as a computer print-out. In either case, the presentation is in a format considered to be of greatest use to the ventilation engineer. Figure 3-1 is an example presentation.

3.2.2 France

Initially, the degree of gas emission in roof strata was considered by CERCHAR to be 100% to the zone of influence boundary positioned at 100 m above the seam being worked. It was assumed that no methane above this boundary entered the mine workings. In the floor strata, the degree of emission was considered to decrease with inverse proportionality, to a boundary at 100 m below the seam being worked. The shape of the zone of influence was considered to be a rectangular rhombohedron based along the length of the coal face. To complete the model, 50% of the desorbable gas content of the worked seam was considered to enter the ventilating air. The model was tested by comparing actual and predicted emissions.

Work completed in 1977 has improved the model. The geometry of the zone of influence has been revised as a result of the field measurements. Gas content equivalents for sandstones have been revised and minimum remnant gas contents for coal seams within the zone of influence have been identified.

The revised method has been correlated with actual field results and it is estimated that the accuracy of the prediction technique is better than ± 20%.

3.2.3 Belgium

The method adopted is a modification of the CERCHAR technique. For gas emission in roof strata the CERCHAR method is adopted. For emissions from floor strata, a boundary of 50 m has been adopted with the degree of gas emission considered to be 100% in the first 20 m and reducing to 0% in the remaining 30 m. The gas content of both adjacent coal seams and other strata are included in the prediction technique. In Belgium mines, methane make from non-coal strata can represent 50% of the total gas emitted. Research work is being undertaken to develop the relationship between the emission zone and mining conditions.

3.2.4 Federal Republic of Germany (FRG)

Three methane prediction techniques have been developed and are in use. These are the methods of Flugge, Schultz and Winter.

- **Flugge,** who considers the flow of methane into longwall mine workings from triangular prisms above and below the seam being worked. The internal angle of the floor prism is constant, but the roof prism is dependent on the intensity of methane drainage practised.

- **Schultz,** who models emission from a semi-cylinder superimposed on the workings. The diameter of the cylinder, and thus the Zone of Influence, are dependent upon face length. A rectangular zone, 20 m in depth, is considered for emission from floor strata.

- **Winter,** who models the degree of emission in the roof and floor directly from rectangular zones, which vary in height. A **weakness number** is applied to individual stratum dependent upon the ease with which they permit methane flow.

The three techniques are illustrated in Figure 3-2.

Borehole measurement programs undertaken by Koppe have refined predictions of gas flow from the floor and his emission graphs are now used in the FRG.

Programs which correlate field results with the prediction techniques are currently being implemented.

3.2.5 Poland

The development of Polish prediction methods is centered at the Mining Research Institute in Katowice and is based on work in the Barbara experimental mine. The function of prediction is to enable future planned workings to be categorized according to anticipated methane emission levels. As with other empirical methods, the Polish require emission data relating to:

- the seam being worked
- coal in transit from the working face
- overlying and underlying strata

Both direct and indirect methods are used to determine the in-situ gas content of coal seams. With the direct method, samples are taken from the newly exposed coal face, or drill chippings are taken from boreholes 3-4m deep, and placed into hermetically-seald containers for laboratory testing. With the indirect method, mean sorption isotherms are used to determine gas content. Intensive sampling programs are undertaken to achieve an acceptable level of accuracy for in-situ gas determinations. The coal seam is then categorized on the basis of the in-situ gas content.

In developing the specific emission for a working face, a norm of absolute gassiness has been established. This is the predicted volume of methane released from the seam being worked and emitted from adjacent coal seam sources for a standard output of 500 tonnes per day. Nomograms have been developed for daily outputs differing from the norm. The nomogram is based upon the relationship:

$$Q = a W + b \quad m^3/min.$$

where:

W = planned daily output, tonnes/1440 minutes
a = 0.0277 x Q500
b = 0.38 x Q500
Q500 = absolute gassiness, $m^3/min.$

Methane emission from adjacent seams is derived using the degree of gas emission curves developed for the Barbara method. The maximum degrees of gas emission from the roof and the floor are 65% and 54% respectively. These appear low when compared to Western European methods. The Barbara method considers only coal seams as methane sources, an approach also taken in the MRDE technique. Also, a coefficient of irregularity is used to account for peaks in methane emission.

As an alternative to the degree of gas emission method for the calculation of emission from adjacent coal seam sources, there is used a method based on gas pressure measurements within the coal seams. This approach is based upon work by Ajruni relating to the influence of seam extraction on methane released from adjacent strata. This work on "the field of strata gas pressure" enables the residual pressure of adjacent coal seam sources to be predicted. Residual pressure curves have been developed for both roof and floor sources. For prediction purposes the original methane pressure is superimposed onto the residual pressure curve and the differences of original and residual pressures noted. Methane emission resulting from these pressure reductions are derived from the adsorption isotherm of the coal seam source. The total volume of methane emitted into the mine workings is the sum of the volumes from the individual methane sources.

The prediction techniques were subjected to extensive testing to assess their accuracy. The results of testing indicated that the mean difference between forecast and measured methane emissions did not exceed 30%.

3.2.6 U.S.S.R.

Work in the U.S.S.R. has resulted in the development of a standard method of ventilation design in which methane prediction is a vital element. The prediction techniques have been developed to forecast the total methane emission into a coal mine. The method considers individually elements of emission into working districts, development roadways and old workings.

Two methods are used to determine the methane emission from coal seam sources above and below the seam being worked. The first involves calculation of residual pressures in the "field of gas strata pressure" as is done in Poland. Again, dip of seam, distance from the seam being worked, and extracted height of the worked seam are taken into consideration. Adsorption isotherms are applied to give the initial and residual gas contents of the coal seam source. Emissions are summed to give the total emission from adjacent seams.

The second method is similar to Western European methods in that a zone of gas emission and the concept of degree of gas emission are considered. A rectangular emission zone is assumed with this method of prediction. The boundaries of the zone are variable and are dependent upon:

- thickness of coal extracted
- dip of strata
- waste caved or stowed
- longwall face life

The degree of gas emission as a function of distance from the seam being worked for the Lidin method is shown in Figure 1-10.

Experience in the U.S.S.R. indicates that methane emission from surrounding strata, other than coal seam sources, is some 10% - 15% of the total emission into the working area and allowance is made for this in prediction calculations. Gas emission from old workings contributes between 5% and 20% of the total emission from sources other than the seam being worked and these values are in-built into the prediction model.

The technique accommodates the dip of the strata and waste fill practice (caving or stowing). Gas emission is derived from the concepts of relative thickness and desorbable gas content.

3.2.7 United States of America

Work funded by the U.S. Bureau of Mines has been directed towards the development of a computer oriented model to simulate methane flow from coal seams and intervening strata into mine workings. The model provides the flow equation as a second order, non-linear, partial differential equation, which is solved by computer-based numerical analysis.

The effect of water flow on permeability to methane flow is also the subject of a study funded by the Bureau. This study is to develop a model which simulates both single phase methane flow and two phase water/methane flow in a coal seam during mining operations. Two computer programs have been developed. The output from the programs gives a prediction of the methane concentration gradients and pressure distributions within the coal seam and the flow of methane, or water and methane, into the mine workings as a function of time.

3.3 METHANE PREDICTION DEVELOPMENTS SINCE 1977

3.3.1 General

European investigators have continued to develop the empirical methods described in Section 3.2 of this report. The individual prediction techniques have continued to be tested against field results and the prediction models refined as this data base has increased. Table 3-1 shows the data base used in each European prediction technique. The USA has continued to pursue a theoretical approach supported by computer modelling and has advanced to the stage where the models are to be tested against actual methane emissions at three selected test sites.

3.3.2 United Kingdom

The practical and theoretical work undertaken at MRDE has been aimed at obtaining the accurate calculation of the **specific emission** for a working district. This is the total volume of methane entering the district from all sources per tonne of coal extracted at the coal face (M^3/t). Identifying and accurately quantifying the individual sources provides the basic data for the MRDE prediction technique.

The method has been tested at a number of trial sites. At each site the necessary basic data has been derived and methane and air monitors installed to measure actual emission levels. An example of the emission calculation is shown in Table 3-2. The contributions to total district emission from all roof and floor sources are shown in Figure 3-6. The cumulative line is useful in deciding the optimum lengths for firedamp drainage holes.

By 1984, prediction techniques were showing a high degree of agreement between prediction and measurement. Mean percentage errors were of the order of 3% but the standard deviation is of the order of ± 20%. This was thought to be largely due to random errors in measurements and to unexplained variations being superimposed upon the weekly advance variable. The source of these random errors is the primary focus of current research.

MRDE use Airey's model of methane emission in mining operations. The model considers emission from all coal seams in a thomboidal zone of influence with boundaries at 200 m above and 100 m below the seam being worked. There are three basic elements in the MRDE prediction model:

- The **degree of emission,** for coal seams within the boundaries of the zone of influence, decreases with distance from the seam being worked.
- Emission from the seam being worked is dependent upon the **rate of advance** of that working.
- The **total methane content** of each coal seam source is applied i.e. the quantity of methane which would desorb to zero partial pressure.

Concurrently with the developments in the prediction model, advances have been made in the techniques for measuring the gas content in coal seams. Also, the NCB exploration borehole program has provided information relating to the distribution of gas content in coal seams.

Gas content measurement is done by the direct method, and a recent inexpensive advance has been made for this testing method. The modification consists of taking large numbers of small samples (30 to 40 g) from the working faces underground rather than drill samples. This permits detailed study of the variations in gas content within the seam and correlation of these variations with petrographic, moisture and ash contents of the samples.

The sampling program has identified a considerable spread in methane content values obtained from coal samples, taken from the same seam, in close proximity to each other. The program has indicated that a major cause of this variation is connected with the crack structure endowed on a coal lump by the maceral **fusinite.** It has been found that coal lumps with high fusinite content tend to desorb gas at unusually high rates and so have lower gas content, when sampled, than lumps which contain little fusinite.

The underground gas content data is treated statistically to overcome the problem of variation co-efficient in the sample. The combination of multiple, easily collected, samples taken at the coal face and statistical analysis of their gas content measurements is considered to be of little value for the estimation of the virgin gas content of seams considered to have a relatively high permeability such as those that occur in the United States of America. No testing has been done to prove the validity of this speculation.

The direct method is also applied to coal samples taken from surface exploratory boreholes. Seams have been sampled over extensive areas and derived information has been used to allocate individual gas content values to each seam in a sequence at a given site. In a typical sequence of strata, measurements have shown that the methane content of seams increases by between 0.5 and 1.1 m^3/tonne per 100 m increase in depth.

The **degree of gas emission** from coal seams in the adjacent strata is derived by Airey as a function of distance from the seam being worked (Figure 3-3). The abscissa of the graph represents the time which has lapsed since the working place passed the position for which the emission is calculated. For the outbye end of the return gate this is the age of the district.

MRDE has translated the Airey curves into a more conventional form (Figure 3-4). It was found that the computed curves for different depths of working were of similar shape so one basic set of curves, for 900 m depth, is used together with a correction chart for other depths.

Emission from the seam being worked decreases with advance rate and has been found to be typically 50% at a weekly face advance of 16 m. Emission in transit from coal of a typical size produced by a shearing machine was 17% during the first 20 minutes, which is a general approximation to the time the coal is in transit in intake air.

Work is being done on developing criteria for calculating the potential quantity of emitted gas from adjacent seams which may be drained by a firedamp drainage system installed in the seam being worked. Criteria will be modified as practical measurements are taken as the program progresses. Figure 3-5 shows the concept adopted for this work.

Investigations into the **Coefficient of Irregularity** have substantiated a factor of 1.5 for peak methane concentrations when compared to the average level.

3.3.3 Federal Republic of Germany (FRG)

Work has been concentrated on investigations into the gas emission process and into the parameters of the gas emitting zone for workings in virgin surrounding conditions. Previous work on the physical prediction model had identified the three classical elements in the empirical technique:

- gas-emitting zone,
- degree of gas emission,
- gas content.

German researchers are satisfied that suitable techniques were in place for the measurement of gas content. However, previous investigations on the gas emitting zone (Noak) and on the degree of gas emission (Koppe, 1975 and Noak, 1980) had produced acceptable results only for the floor strata below the worked seam and not for the roof strata in the zone of emission.

For roof strata, insufficient data were available and the curves of the degree of gas emission were derived indirectly from measurements relating to rock mechanics (Schultz, Winter and Flugge) and not from directly derived gas emission measurements. This resulted in under prediction of gas emission for working panels in virgin conditions of up to 50%.

To develop a more accurate method, a research program was implemented. This program investigated the flow of the gas from strata overlying the seam being worked during the different phases of the coal extraction process. It also investigated the parameters of the gas emitting zone by measuring the spatial distribution and time dependence of the residual gas content.

Five test sites were used. All were fully caved longwall faces in flat or moderately inclined seams of medium thickness. The investigations into the evolution of the gas emission process revealed that the roof boundary was in excess of 300 m from the seam being worked. These investigations also found that the maximum gas emission occurred in the zone of maximum influence, i.e. above the waste of the working face with an angle of influence of between 70 and 80 degrees to the horizontal. The investigation also revealed that permeabilities for gas flow up to 82 m above the seam being worked were comparable at the different test sites and were two or three orders of magnitude higher than those at 200 m and 300 m above the seam being worked.

These results indicated that it was questionable as to whether a relationship between the degree of gas emission and the perpendicular distance of the source above the worked seam could be used for the prediction purposes. A more uniform pattern emerged when the **residual gas pressure** was used in relation to the perpendicular distance from the worked seam. The work identified three sub-zones in the roof. It was found that the gradient of residual gas pressure in the different sub-zones appeared to be dependent upon permeability in each zone and hence on the fracture pattern of the strata. Further investigation is being undertaken into this phenomenon.

A further important finding was that for the prediction of gas emission, the total gas content of the seam being worked should be used and not the desorbable gas content. This is consistant with British (MRDE) practice.

On the basis of the results of the investigation, the FRG prediction technique incorporates the gas pressure method and converts the gas pressure to gas contents using the Langmuir adsorption isotherm equation. The technique incorporates emission from rock strata other than coal seams but this appears to be a correction to align prediction with actual measured quantities.

3.3.4 France

No significant advances in prediction techniques have been published since 1977. Residual gas pressure is used in the CERCHAR prediction technique.

3.3.5 Belgium

No significant advances in prediction techniques have been published since 1977.

3.3.6 Poland

The Polish coal mining industry fully reviewed the available methane prediction techniques and their applicability to Polish mining conditions. Included in the review were:

- Graphic methods of Schultz, Stuffken and Winter
- Western European empirical methods
- Methods used in the U.S.S.R.
- Formulae for calculating methane emission into galleries (U.S.S.R.)
- Barbara Experimental Mine method.

The above techniques were comprehensively tested against measured methane emissions from controlled field trials. One conclusion of this investigation was that no single prediction technique yielded the best results for every mining/geological environment. However, the tests did confirm the need to precisely identify the methane bearing zones and the stratigraphic system of the surrounding strata. Following this investigation, the Barbara Mine method was chosen for use in Poland.

For the Barbara method of methane prediction, the methane content of the coal seam is determined by direct sampling. Multiple sampling is done to provide a sufficiently accurate data base for determining an accurate in-situ gas content for each coal seam source and also the spatial distribution of methane in the surrounding strata.

Barbara Mine has established a functional relationship between the methane content of a coal seam and its volatile content, namely:

$$y = ax + b$$

where:

y = methane content of seam m^3/t
x = volatile matter content
a = -0.277
b = 11.76

The relationship is shown in Figure 3-10.

For prediction purposes, the following basic data is used:

- geological cross-section showing the distances and thickness of coal seams within the zone of influence of the seam being worked

- schedule of development work and longwall extraction
- coal seam data including moisture content, ash content, volatiles and, where possible, laboratory-derived methane content.

Where laboratory-derived methane contents are not available for individual coal seam sources, Figure 3-10 is used to derive that value.

Data is tabulated in a manner similar to that used in the United Kingdom (Table 3-2) and the gas emissions from the several sources are calculated. The Barbara Mine curves for degree of gas emission are used for overlying and underlying coal seam sources.

Multiple field trials have been carried out to test the accuracy of the Barbara prediction technique. The Mean Difference between predicted and measured gas emission into the working area has not exceeded 30%. This aligns with the degree of accuracy being achieved with other empirical methods.

Investigations into cases where the degree of accuracy was low have indicated that the additional methane is being emitted from porous rock strata not included in the calculation. Further investigation is now proceeding to identify and quantify these sources of methane emission to improve the prediction technique.

Based upon the large numbers of field trials undertaken, it is interesting to note that the Polish mining industry also uses a basic prediction technique similar to that developed by USBM in the United States. With this method, the methane emission from coal seams overlying and underlying the seam being worked is taken as four to eight times greater than the emission from that seam. The method is used only as a practical guideline and does not replace the Barbara prediction technique.

More recently, attention has been directed towards the prediction of methane emission in coal drivages. Previously, the Polish mining industry had used a value of Mean Absolute Gassiness for coal headings. This did not allow for the large volumes of methane released in a relatively short time during the coal winning process, which in turn is dependent upon the drivage method. Investigations are now being made into identifying volume emissions from individual sources during the coal winning process.

3.3.7 U.S.S.R.

Recent work has concentrated on the development of formulae for calculating the predicted methane emission into the working area from the surrounding strata. The formulae take into account a number of factors, namely:

- volume of methane capable of release from 1 m^3 of porous rock
- methane content of seam being worked per cubic metre of coal extracted
- longwall face lengths
- goaf length in the longwall panel (from face starting point)
- longwall face life (days)
- derived constant K.

The derived constant is dependent upon:

- angle of dip of strata
- depth of the mined seam
- thickness of the seam being extracted
- filtration coefficient expressed in m^2/second.

The accuracy of this technique for forecasting methane volumes emitted from surrounding strata was tested against actual results from 28 working faces. The total methane emissions from these units varied from 1.1 to

57.4 m^3/min. The variation between predicted and actual methane emissions did not exceed $\pm$ 10%.

The work suggested that, in the U.S.S.R., the methane volume emitted from surrounding strata constituted 60% - 72% of the total volume in the working district. These values align with results obtained in Western Europe.

The U.S.S.R. has also developed a statistical methodology for the prediction of methane emission into working areas. The method is based upon the assumption that gas content in any given coal seam increases uniformly with depth. The method is dependent upon accurate ventilation records. The historical data for any given seam is then used to predict methane emissions as that seam is exploited at greater depths, and is derived from the general formula:

$$Q = \frac{H - Ho}{L} + 2 \quad lm^3/\text{tonne}$$

where:

H = absolute depth of planned extraction
H_o = absolute depth from the surface of the upper boundary of the methane emission zone
L = methane content gradient

The method required knowledge of the methane content of the coal seam and the derivation of the zone of methane emission.

In developing the data base from existing workings it is necessary to calculate:

- the average monthly methane emission from return airway measurements in the working district

- the average monthly methane concentrations
- the average monthly volume of air circulating the working district
- the average daily output from the district.

The average methane emission per tonne of coal mined is then derived from the above data and plotted on the mine plan. From the mine plan plots, iso-emission contours are developed for the coal seam. These are developed for any given mining level and then further developed to cover the whole mine. From the contouring, predictions are then made for planned deeper workings.

More recently, work has been directed towards accurately predicting methane emission in development headings. This work aligns with that done in Poland, but appears to be further advanced. Investigations were made in headings advanced by blasting and those driven by roadheading machines. The parameters selected for the data base were:

- mining method
- rate of advance
- methane content of coal
- time the mined coal remains in the heading
- volume of air at the face of the heading.

Site investigations and observations were carried out under differing mining and gaseous conditions over several years. Nomograms based on the investigations have been developed and are used for predicting methane emission in development headings.

3.3.8 United States of America

In the United States work since 1977 has continued as before on phased work programs to develop a comprehensive computer modelling method for methane prediction.

In phase 1, the work included the development, demonstration and documentation of a computer model, MINEAD, for the flow of methane and water in coal strata for geometries corresponding to an advancing face and a coal pillar. Trial sites have been selected for the measurement of methane emissions during longwall mining and room-and-pillar operations. These will test the accuracy of the models.

In phase 2 of the work, the development of a two-dimensional model is being undertaken. This simulation, involving finite element methods, considers the vertical section through the center of the working. Anisotropic permeability is taken into account in addition to the compressibility of the gas. The flow of methane through the boundaries of each element is calculated, allowing for storage and desorption effects. In the more sophisticated programs, methane drainage boreholes can be included (O'Shaughnessy, 1980). Examples of the graphical output from such a program are illustrated on Figure 3-7, 3-8 and 3-9. The isobars shown represent:

- a normal condition
- the build-up of pressure below strong impermeable band (a potential outburst condition) and
- the effect of sudden fractures through this band (an outburst situation).

Similar programs have been developed for methane degasification schemes using surface boreholes (Niou, 1985).

3.4 APPLICABILITY OF PREDICTION TECHNIQUES TO CANADA

3.4.1 United States of America Approach

Apart from the basic USBM method of prediction described in a previous section, researchers in the United States of America are applying computer modelling to methane prediction. Although these simulation techniques may ultimately provide accurate and detailed predictions, they are used for research rather than routine prediction work. The current extent of development is not appropriate for application to practical mining operations. Additionally, they require data which may be difficult to obtain such as multi-dimensional and temporal variations in the permeability for each stratum. To date, only limited field trial work has been done to test the accuracy of modelling.

The use of this method is relatively costly since current finite element programs are expensive in computer storage and running costs. Given that this technique is relatively untested and is expensive, it is considered unsuitable for Canada at this time.

3.4.2 U.S.S.R. Approach

The U.S.S.R., like other European countries, developed an empirical approach. Recent work in the U.S.S.R. has concentrated on an elaborate mathematical/statistical analysis of the basic derived data (Ajruni). A high degree of accuracy is claimed for this technique with variations between predicted and actual emissions not exceeding ± 10%. To apply the technique requires the painstaking development of a data base from ventilation records over a number of years. Sufficient information must be obtained over a large geographical span to allow the accurate determination of the methane content gradient for the coal seams to be exploited. This work is symptomatic of large, mature coalfields where considerable time and effort have been devoted to the ventilation aspects of the mining operation and an extensive, historical data base has been derived.

However, the statistical work has substantiated the order of magnitude assumptions for the contribution from adjacent sources in the British, Polish, German and USBM methods. These are that the order of magnitude of the contribution to total methane emission from adjacent seams varies from 4-9 relative to methane from the seam being worked. The U.S.S.R. order of magnitude is 6-7.

Essentially, the U.S.S.R. developed an empirical approach to methane prediction and developed a comprehensive data base over a number of years. Development work on the derived data base has resulted in prediction calculations providing an acceptable level of accurcy. It would appear unlikely that sufficient data is in place in Canada at this time to directly apply this mathematical approach. However, as the Canadian data base is put in place, this approach would appear to be a logical development in prediction methodology.

3.4.3 European Approach

The European prediction techniques adopt the same basic principles. All are directed towards longwall mining operations. Each of the methods considers the same basic parameters, namely:

- Gas content of the coal seam being worked.
- Gas content of other coal seam sources and, where pertinent, of non-coal stratum.
- Zone of gas emission in both the roof and floor strata.
- Degree of gas emission from adjacent seams and strata.

Inherent in all European empirical techniques is a detailed knowledge of the position and thickness of the individual stratum surrounding the seam being worked.

Differences in the techniques are in their definition of the zone of gas emission and the derived variation of the degree of gas emission within the zone. These differences result from the site specific circumstances prevailing in each case and, as such, are to be expected.

All the techniques are based on an accurate value of the in-situ methane content of the seam being worked. No prediction technique can be more accurate than the accuracy of the gas content determination. This, of all the data required for methane prediction, is the only element requiring practical measurement. Both direct and indirect methods of determining desorbable gas content are used and, to a large extent, local circumstance determines the method selected.

3.4.4 Canadian Experience

To date, no concerted effort has been made to develop a methodology for methane prediction in Canadian underground coal mines. However, there has been on-going work into the mechanics of methane retention and flow in both coal seams and surrounding strata (Patching, Fisekci, Barron, et al).

More recently the prediction of methane for Cape Breton mining conditions was attempted by a team of investigators form the College of Cape Breton (Arseneau et al). The investigators used the MRDE prediction technique as a model and, despite having incomplete local information, they concluded:

> "Notwithstanding the many approximations that were made and the inadequacy of much of the available data, correlation between calculated methane make and measured emissions in Lingan 4 East is encouraging. Preliminary results certainly

> suggest that efforts to obtain refined information on Cape Breton coal are warranted and that the MRDE method of methane prediction holds considerable promise for local coal mining."

Concurrently work has been undertaken by the Canadian Centre for Mineral and Energy Technology (CANMET) to analyse methane emission trends in the Harbour Seam at two Cape Breton mines (Konda and Kochhar). The reports stress that the data used is "soft" and also that, while methane surveys of the type undertaken are useful for ventilation status and methane emission pattern, they are not satisfactory for methane emission forecasting. However, certain tentative conclusions could be drawn from the studies, namely:

- A relationship between methane emission rate and depth of workings (Figure 3-11).

- A relationship between methane emission rate and age of working district (Figure 3-12).

- The order of magnitude of the contribution to total methane emission from adjacent sources was relative to methane emission from the seam being worked.

Of equal importance, these studies did identify areas where additional information was required, for example:

- In-situ methane contents of the Harbour Seam and adjacent coal seam sources.

- Methane migration paths in the relaxed zone.
- Methane emission from the coal front.

Work has been done in British Columbia and Alberta to determine the desorbable gas content of several coal seams (Feng, Augsten and Cheng). The USBM direct method of measurement was applied to samples from surface boreholes. Desorbable gas content and residual gas content values were obtained from the samples and the lost gas content calculated. The specific gas content of the coal seam was then estimated.

The implications of Canadian measurement and prediction work to date and its impact on the preferred prediction technique are discussed in the following sections of the report.

TABLE 3-1 FACTORS TAKEN INTO ACCOUNT BY VARIOUS PREDICTION METHODS

No.	Factor	Method							
		Stuffken Netherlands	Schulz GFR	Flügge GFR	Winter GFR	Gunther France	Lidin USSR	Barbara Poland	MRDE UK
1	Gas content of adjacent seams	1	1	1	1	1	1	1	1
2	Gas content of other strata		1	1	1	1			
3	Thickness of adjacent seams	1	1	1	1	1	1	1	1
4	Distance of adjacent seams	1	1	1	1	1	1	1	1
5	Face length (determines emission zone)		1	1					
6	Intensity of firedamp drainage			1	1				
7	Dip of worked seam	*					1		
8	Worked seam thickness						1	1	
9	Caving or stowing						1	1	
10	Depth of working	*							1
11	Age of district								1
12	Advance rate of face								1
13	Emission from conveyor coal								1

* Factors used indirectly by Stuffken to calculate gas content values.

Source: Dunmore, 1980

TABLE 3-2 CALCULATION OF EMISSION FROM SOURCES IN STRATA SECTION

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Shaft section –	Gas Content	Distance from		Thickness		Emission ahead of face			Total emission		
Strata sources	(m^3/t)	datum (m)	worked seam (m)	actual (cm)	relative to worked seam	Degree of emission % 0 weeks	$\frac{2 \times 6 \times 7}{100}$ (m^3/t)	cumulative (m^3/t)	Degree of emission % 75 weeks	$\frac{2 \times 6 \times 10}{100}$ (m^3/t)	cumulative (m^3/t)
ROOF TOTAL								$\boxed{10.7}$			$\boxed{28.9}$
coal	7.88		205	8	0.07	3	0.02	10.67	20	0.11	28.88
Swallow Wood	7.94		192	99	0.88	4	0.28	10.66	22	1.54	28.77
coal	8.09		163	33	0.29	5	0.12	10.38	26	0.61	27.23
coal	8.22		137	83	0.74	7	0.43	10.26	34	2.07	26.62
coal	8.27		126	15	0.13	8	0.09	9.83	38	0.41	24.55
coal	8.38		104	58	0.52	12	0.52	9.75	49	2.14	24.15
coal	8.43		95	79	0.71	14	0.84	9.22	55	3.29	22.01
coal	8.56		69	8	0.07	23	0.14	8.39	73	0.44	18.72
coal	8.59		63	28	0.25	26	0.56	8.25	77	1.65	18.28
coal	8.61		58	28	0.25	28	0.60	7.69	80	1.72	16.63
coal	8.65		44	2	0.02	35	0.06	7.09	89	0.15	14.91
coal	8.77		27	5	0.04	44	0.15	7.03	95	0.33	14.75
Parkgate	8.78		25	163	1.46	45	5.77	6.87	96	12.31	14.42
coal	8.82		16	2	0.02	49	0.09	1.10	98	0.17	2.11
Thorncliffe roof	8.90		- 1	25	0.22	52	1.02	1.02	99	1.96	1.96
Worked Seam	8.90	767.4	0	112	1.00					remnant	x17%
Thorncliffe					8 m	99	$\boxed{5.3}$			3.6	$\boxed{0.6}$
		at a weekly advance			12 m	54	$\boxed{4.8}$			4.1	$\boxed{0.7}$
					16 m	51	$\boxed{4.5}$			4.4	$\boxed{0.7}$
coal	9.05		-30	15	0.13	41	0.48	0.48	93	1.09	1.09
coal	9.08		-36	76	0.68	38	2.35	2.83	91	5.62	6.71
coal	9.15		-50	12	0.11	20	0.28	3.11	81	0.82	7.53
coal	9.24		-68	44	0.39	18	0.65	3.76	63	2.27	9.80
coal	9.26		-72	14	0.13	16	0.19	3.95	59	0.71	10.51
coal	9.30		-79	10	0.09	13	0.11	4.06	51	0.43	10.94
coal	9.39		-98	15	0.13	8	0.10	4.16	35	0.43	11.36
FLOOR TOTAL								$\boxed{4.2}$			$\boxed{11.4}$

District T25e
Worked seam Thorncliffe

Colliery Brodsworth
Date 1977

Source: Dunmore, 1980

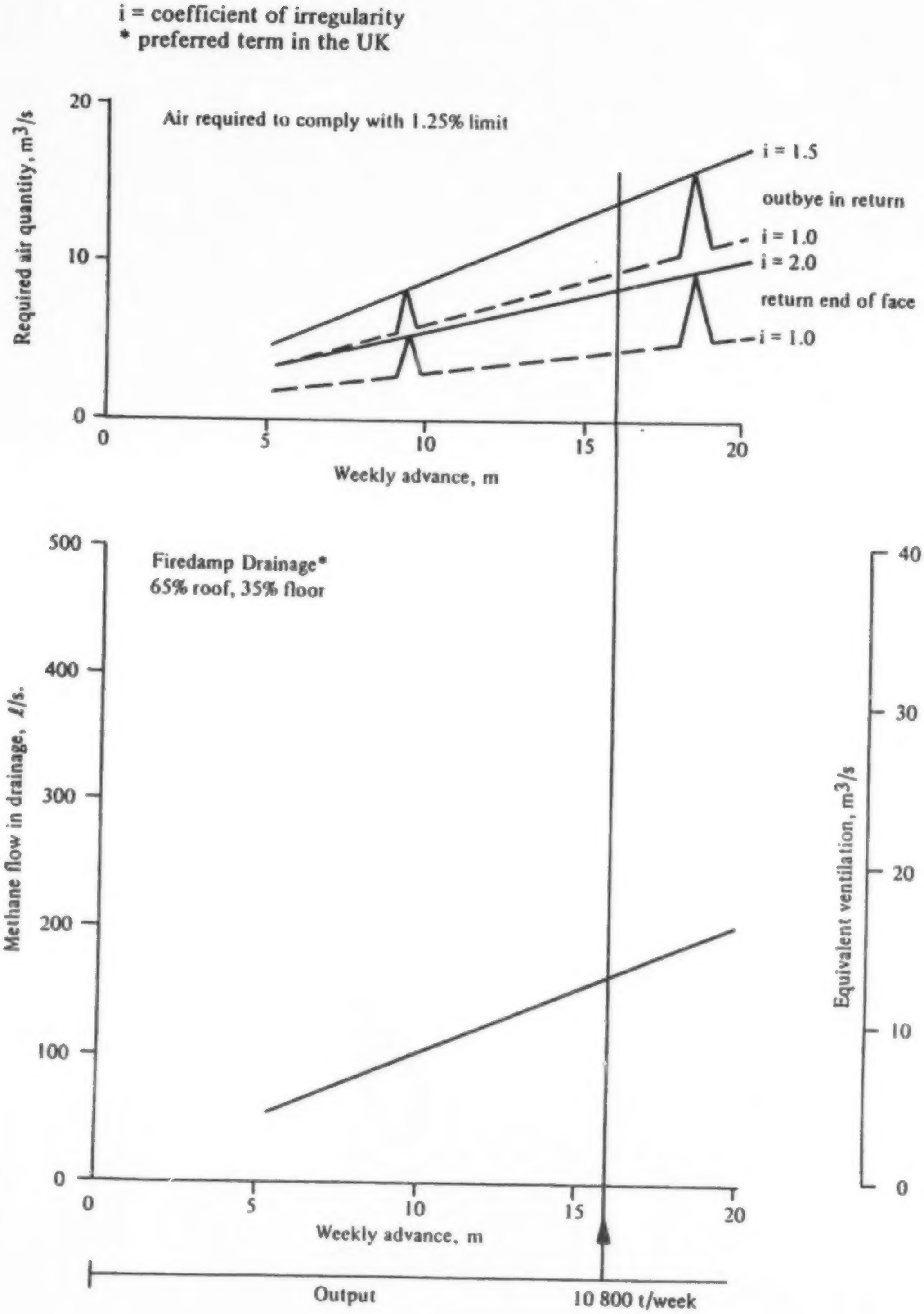


FIGURE 3-1 Example Presentation of Results from MRDE Prediction Method

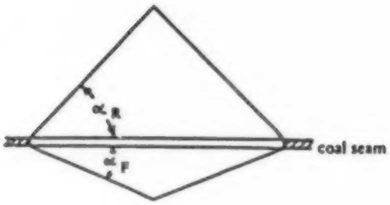
Source: Dunmore, 1980

FIGURE 3-2 Zones of Emission used in FRG

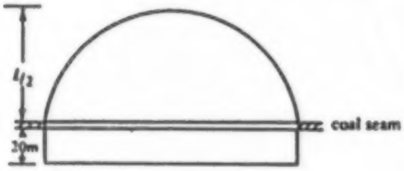
a) **FLÜGGE, Triangular prisms**

	A	B	C
α_R	50 gon	60 gon	65 gon
α_F	25 gon	25 gon	25 gon

A	No drainage
B	Medium drainage
C	Intensive drainage



b) **SCHULTZ, Semicylinder**

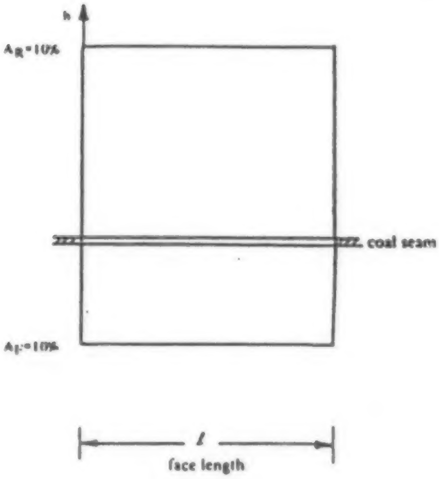


c) **WINTER, Rectangular prism**

$$A_R = 100 \exp(-\mu(h-20)$$
$$A_F = 100 \exp(\mu(h+8))$$

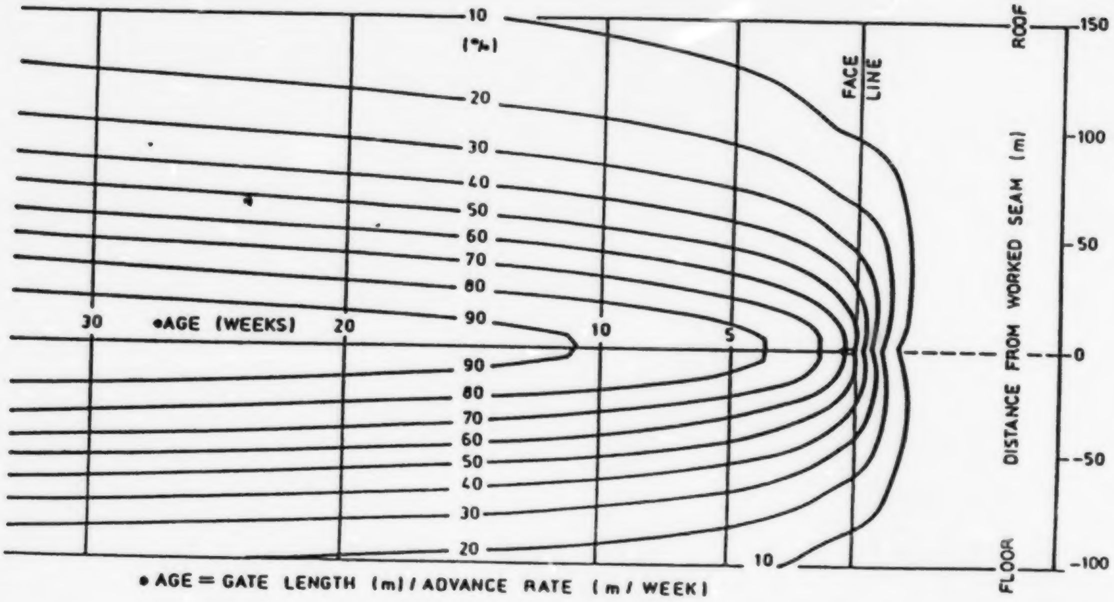
	A	B	C
μ_R	0.016	0.014	0.012
μ_F	0.070	0.050	0.030

A	Strong strata
B	Medium strength strata
C	Weak strata

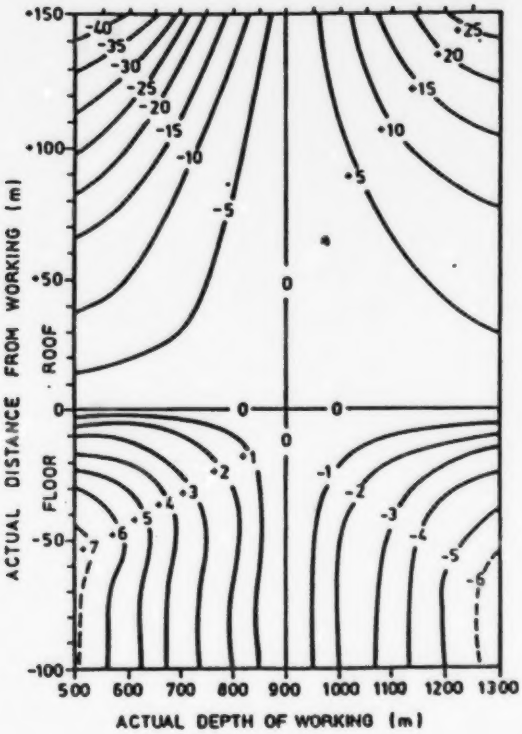


Source: Curl, 1978

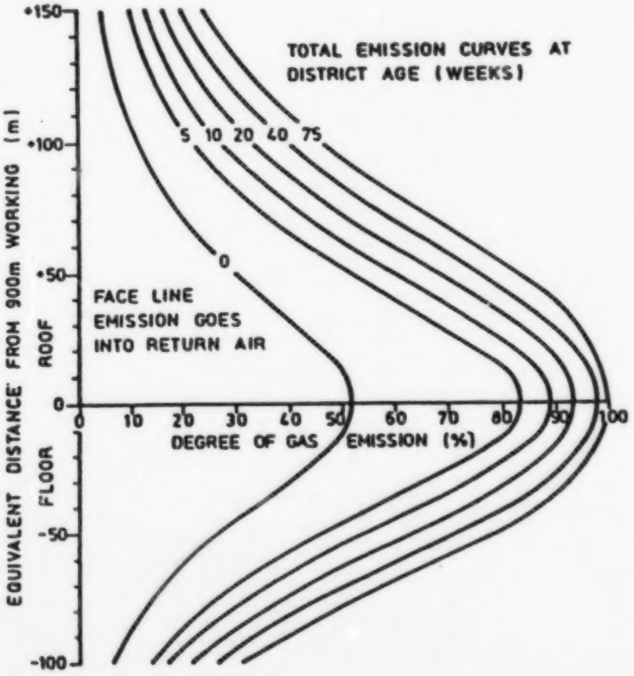
FIGURE 3-3 Degrees of Gas Emission in Roof and Floor



Source: Dunmore, 1980



(a) HEIGHT CORRECTION (m)
BEFORE USING 900m CURVES

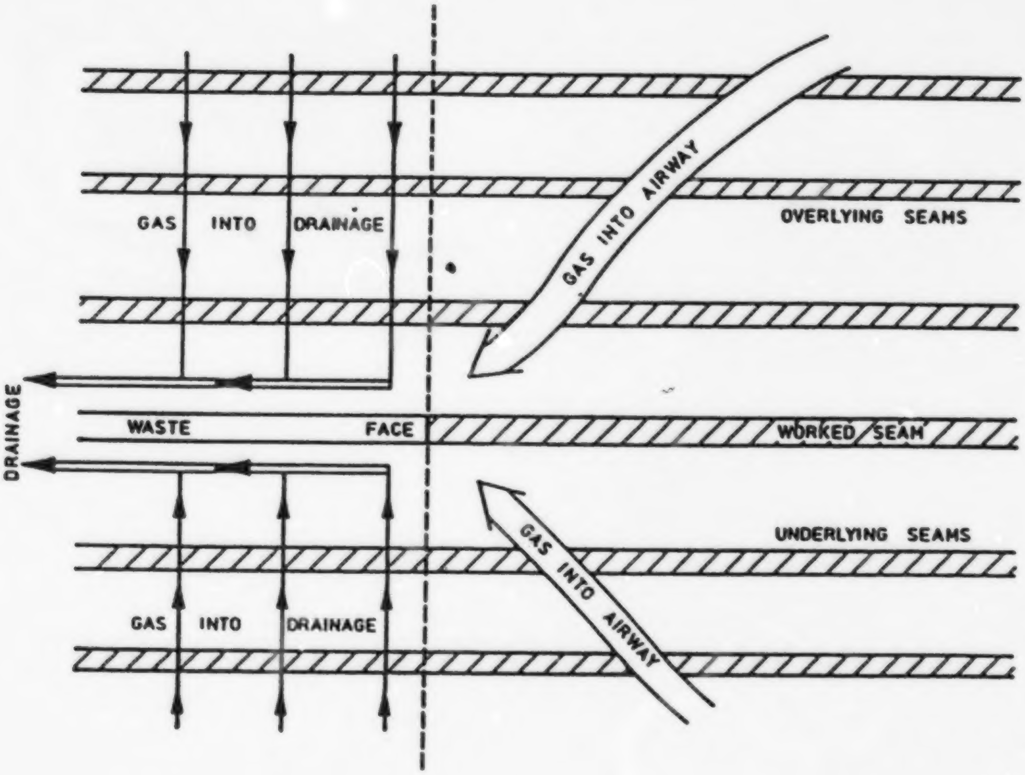


(b) DEGREE OF GAS EMISSION AT 900m

FIGURE 3-4 Degree of Gas Emission Function for MRDE Prediction Method

Source: Dunmore, 1980

FIGURE 3-5 Principle of Firedamp Drainage Calculation



Source: Dunmore, 1980

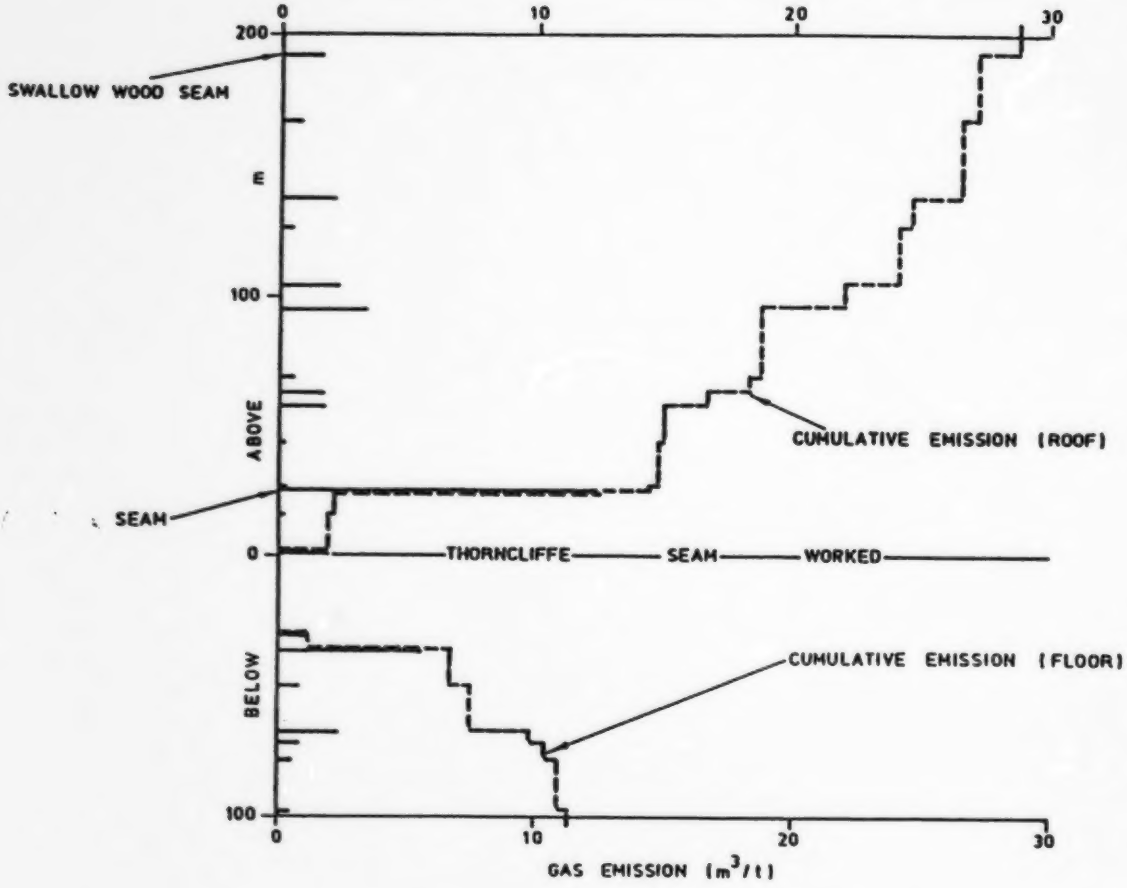


FIGURE 3-6 Predicted Gas Emission for Seams in Roof and Floor Strata

Source: Dunmore, 1980

Source: O'Shaughnessy, 1980

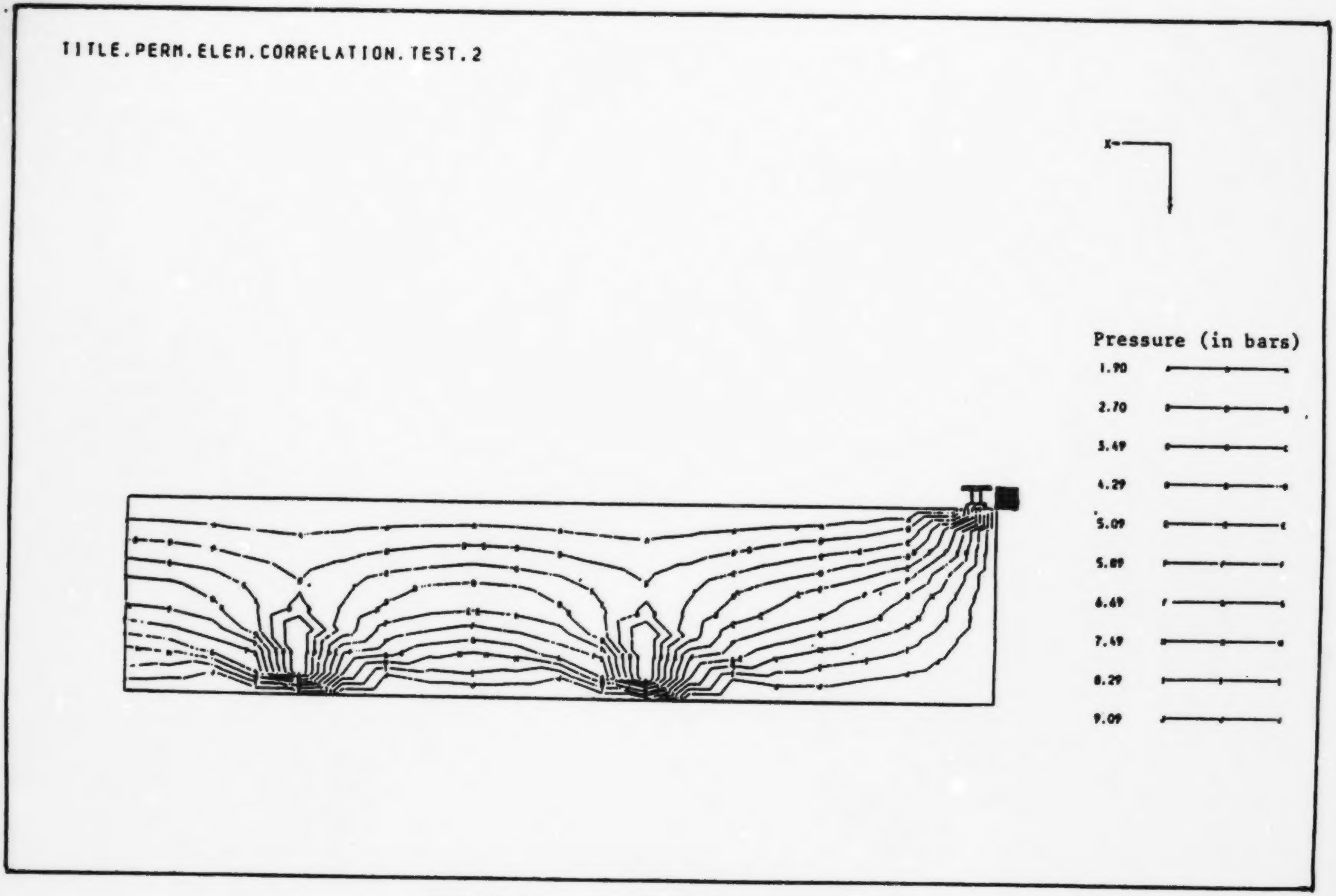


FIGURE 3-7 Permeability Isobars - USA

Source: O'Shaughnessy, 1980

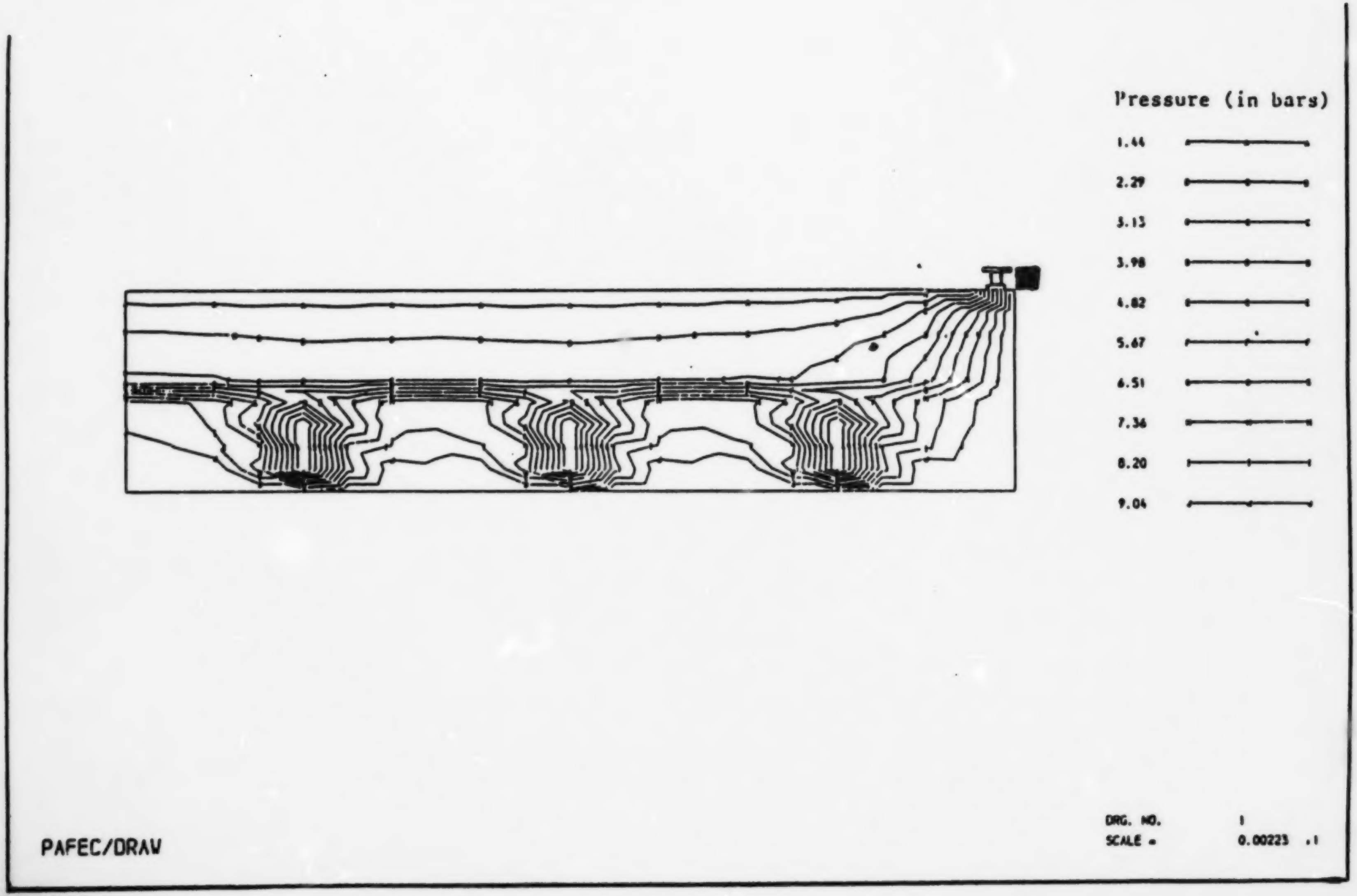


FIGURE 3-8 Permeability Isobars - USA

Source: O'Shaughnessy, 1980

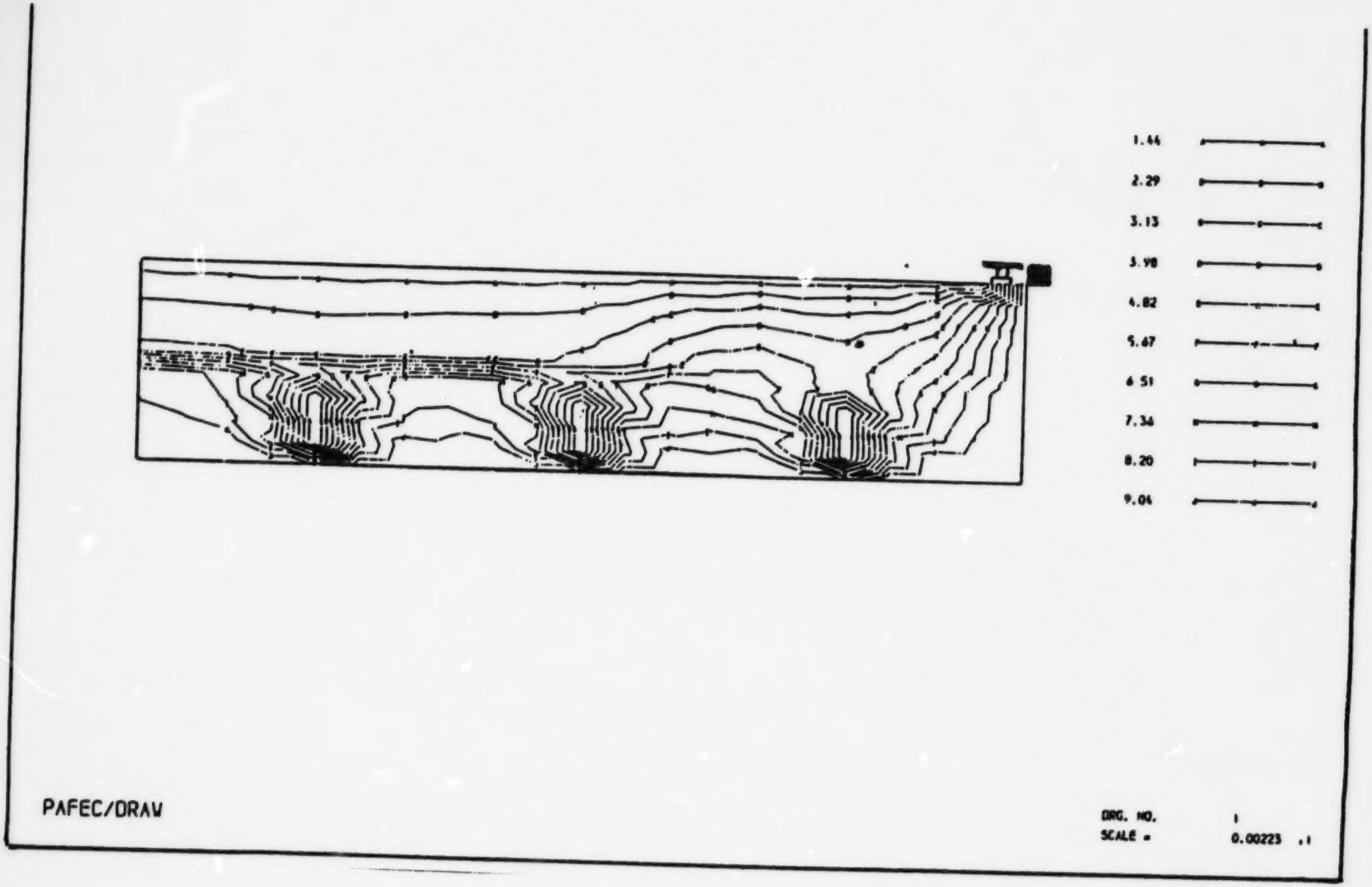


FIGURE 3-9 Permeability Isobars - USA

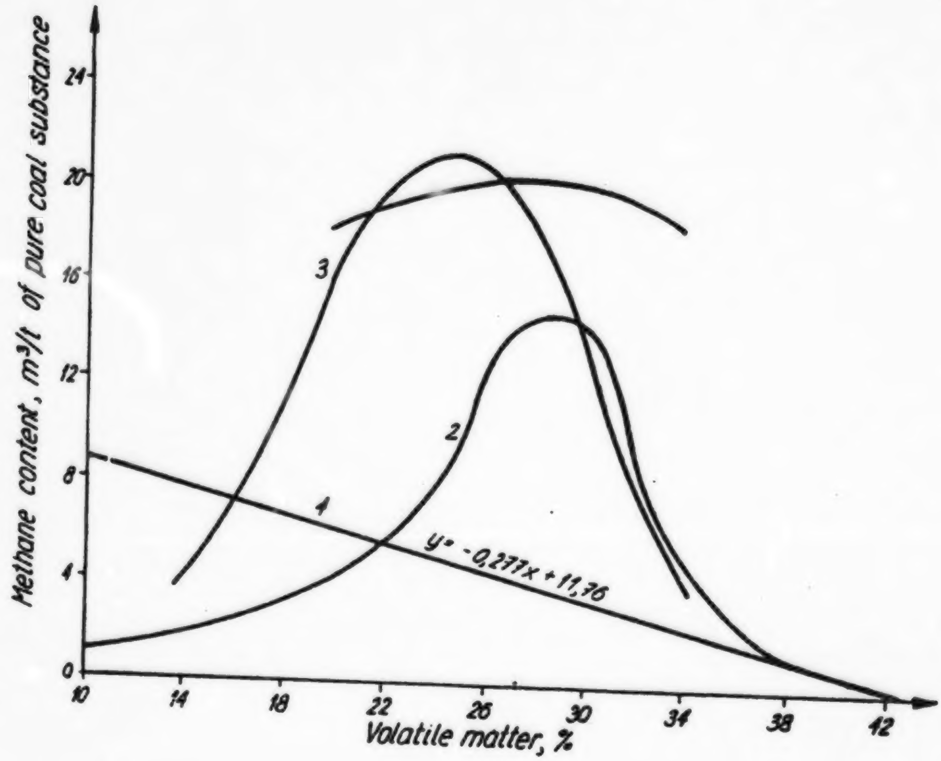


FIGURE 3-10 Relationship between Methane Content in Coal and Volatile Matter Content (in%)

1. according to Schulz, 2. according to Winter,
3. according to Stuffken, 4. according to Barbara Experimental Mine

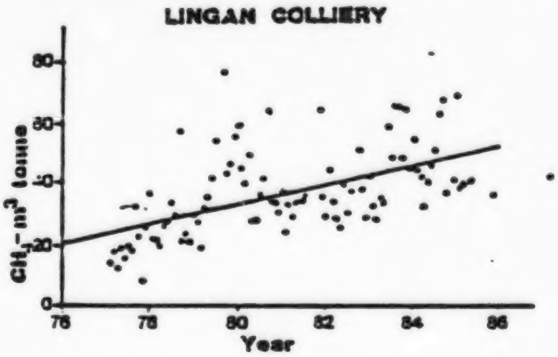


FIGURE 3-11 **Methane Emission Rate Versus Age (Depth) of Mine**

Source: Konda, B.W. and Kotchhar, J., 1985

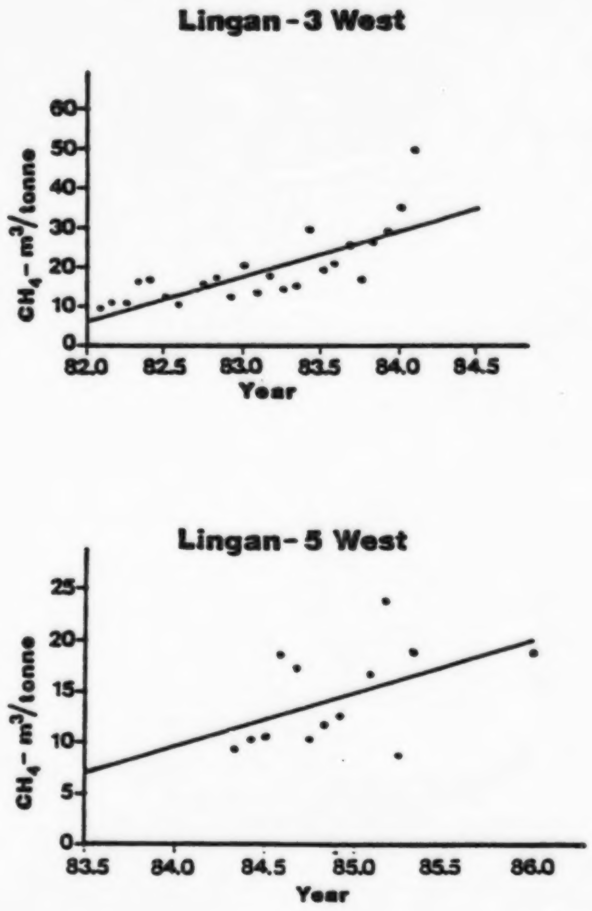


FIGURE 3-12 Methane Emission Rate Versus Age of District

Source: Konda, B.W. and Kotchhar, J., 1985

SECTION 4

CANADIAN APPLICATIONS

SECTION 4

CANADIAN APPLICATIONS

4.1 INTRODUCTION

In determining the relevance of any given prediction technique for Canadian application, it is necessary to assess how the physical model on which the technique is based aligns with Canadian conditions.

Underground coal mining is currently concentrated in the Sydney Coalfield. Limited underground operations do exist in Western Canada, but their future is uncertain and no major new mines are currently in the planning stage.

Accordingly, prediction techniques which address longwall mining in a geological setting similar to the Sydney Coalfield, would appear to have most relevance at this time. However, some prediction methodology has already been applied in Western Canada by direct sampling of cores from boreholes. This type of program should, where possible, be continued to enhance the data base for the future when underground mining is again applied in the West.

4.2 CANDIDATE TECHNIQUES

Prediction techniques have evolved into two main groups, namely Empirical Techniques and Computer Simulation.

4.2.1 Empirical (Analytical) Techniques

In this field the U.S. Bureau of Mines has developed a pragmatic method of methane prediction. For any given region of a coalfield, the initial gas content of the seams to be worked is derived using the direct method of determination. These values are then plotted against actual gas emissions encountered when working the seam in that area (Diamond and Levine, 1981) as shown in Figure 4-1. Provided that historical data is available, this method provides a simple means of obtaining a rough estimate of probable gas emissions. Results have indicated a relatively constant ratio between emission and direct gas content of 6 to 9. This system could be used as a basis for determining the likely order of magnitude of methane emission on a projected working district. Poland has also developed a similar basic technique with derived constants of 4 to 8.

The techniques used extensively in Europe have a more analytical approach. They require comprehensive data bases for the derivation of the prediction model. Derived physical models vary from country to country as each data base is site specific. All models, however, do consider the same methane sources and all have been developed for longwall mining. The models have been programmed for computer application. This allows rapid sensitivity analysis to determine how the precision of each parameter affects the overall accuracy of the prediction.

Each of the techniques has been extensively field tested and subsequently refined and most have now achieved an acceptable level of accuracy.

4.2.2 Computer Simulation

This approach to methane emission prediction is now the main thrust of development in the U.S.A. The method is intended to provide accurate and detailed predictions in any geological and mining environment. However, the work is essentially theoretical and has yet to be proven in the field. Its status as a long-term research project reduces its value in relation to current Canadian requirements. Extensive and costly measurement of a variety of rock parameters, rather than the methane content, is needed to apply this technique.

4.3 SELECTED TECHNIQUES

With the present state of development in prediction techniques, coupled with the potential for free exchange of technical information, a Canadian prediction model can most readily be developed from the Western European techniques. Each of these techniques is based on the same basic calculation, in which every potential source of firedamp in the strata sequence is identified and the quantity of emission calculated for each source. This source quantity is derived from three parameters:

- The initial gas content of the source expressed in cubic metres per tonne of source material.
- The proportion of this initial gas content which it is anticipated will be emitted from each source into the mine workings.
- The thickness of each source relative to the thickness of coal extracted in the seam being worked.

From the parameters, the methane flow rate into the workings is obtained as the product of source emission and mean coal extraction rate, identified as the Specific Emission for the working section under consideration.

4.3.1 Initial Gas Content of Emission Sources

Source gas content is the only practical measurement required in the prediction methodology. It is important that the correct method of measurement be chosen if accurate prediction results are to be derived. There are two basic methods of measurement:

- **The Direct Method,** in which coal samples are taken from the seam and placed in sealed containers. The inherent gas content is released for measurement by crushing and pulverising the samples in a sealed mill. Corrections are made for gas loss prior to sealing the sample and for the quantity still sorbed by the coal at final mill pressure. Samples are taken either from borehole cores from the seam or by progressive sampling from the exposed coal face.

- **The Indirect Method,** which makes use of source gas pressures measured in-situ from sealed boreholes and laboratory-derived sorption isotherms.

Both methods are dependent upon the permeability of the source material and its effective porosity. Direct sampling may not be effective in high permeability coals as the corrections for gas loss prior to sealing the sample become excessive and impinge adversely on the accuracy of the results obtained. Indirect sampling requires a perfectly sealed borehole for accuracy and the effective permeability, i.e. crack structure of the source material, has a major impact on effective sealing. Moisture content is also a critical factor affecting the accuracy of indirect measurements as the isotherm relationship must be established at the same moisture content as that prevailing in the source material. Small changes in moisture content have a marked impact on the firedamp sorption capacity of coal and correlation between in-situ and laboratory moisture contents is therefore highly sensitive.

Comparison of the sensitive features of both methods of measurement indicate that the direct method is probably more accurate and reliable than the indirect method. The selection of sampling technique and methodology when applying direct methods requires investigation for the Nova Scotian coal seams.

4.3.2 Degree of Gas Emission

The major sources of gas emission are considered to be contained within a zone of influence having boundaries at 200 m above and 100 m below the seam being worked. In relation to the degree of gas emission from sources within this zone, differences between prediction techniques are in the curves which have been developed (Figure 1-10). Curve variations are the result of the combination of mining factors utilized in any given method (Table 3-1). The general consensus in Europe is that emission is considered from rhomboidal blocks extending to the boundaries of the zone of influence, when the emission function is considered to be zero. A number of the methods factor gas emission from non-carbonaceous strata in the zone. Unless there is direct evidence to support such emissions, this factor is questionable.

In the Sydney Coalfield, workable seams lie in the upper Carbonaceous series. Four workable seams, the Lloyd Cove, the Hub, the Harbour and the Phalen lie in a stratigrahic column of some 300 m (Table 2-1). The seams are separated by interbanded materials ranging from mudstones to sandstones. Emission sources in this series should be considered for all seams from the Point Aconi which is sited some 80 m above the Lloyd Cove, to the Emery seam positioned 50 m below the Phalen.

In considering the individual techniques in relation to degree of gas emission, the MRDE method does take into account two factors of prime importance, namely the rate of advance and the age of the working district. The method also has the distinction of being based on a coherent physical theory (Airey). Also, a continuous and continuing program is in place for refining the technique. From the body of information available, it appears that the MRDE model should be used as the basis for an initial Canadian prediction technique. However, German methods do include two factors which could have direct relevence to Canadian longwall operations. These being the effect of face length on the boundaries of the zone of influence and the effect of methane drainage on those same boundaries. Both are factors which should be considered in any Canadian prediction model.

4.3.3 Gas Emission from the Working Seam

A significant contribution to the total emission comes from the seam being worked. The Airey curve (Figure 1-5) can be used as a basis for this calculation. However, emission from the seam is a function of both the natural permeability of the coal and its mining-induced permeability. Therefore, the Airey curve may not be directly applicable to the Nova Scotian coal seams and a petrograhic program is required in this area.

On balance, the MRDE method does provide a sound basis for developing a Canadian prediction technique. A number of the parameters require investigation in relation to their applicability to Canadian conditions and these are addressed in the following sections of the report.

4.4 DEVELOPMENT REQUIRED

Immediate development work must be aimed at examining and analysing present emission patterns in the existing conditions of working districts. This will provide the basis for determining future programs of laboratory and field work, which will derive the physical model to be used in the prediction technique. The initial examination should include:

- Review of the ventilation records that exist for the seams being worked. The methane emissions should be logged relative to rate of advance, level of production, age of district, depth of workings and length of coal face.

- Geological mapping of the cleat and joint patterns and the orientation of the workings in relation to those patterns.

- Examination of exposed coal surfaces for the presence and distribution of fusinite.

- Examination of coal analysis data for coal seam moisture content.
- Position of abutment zones and location of stress relief zone.

Analysis of the ventilation records will allow alignment of workings in the seam which have similar rates of production, geometry and depth. The aligned records should be tested to assess if they display general relationships in relation to the individual parameters. Variances in results can be examined in relation to the geological and physical factors investigated in the development program.

This basic work will aid identification of the parameters to be investigated in subsequent programs which will result in the derivation of a meaningful physical model on which to base the prediction technique.

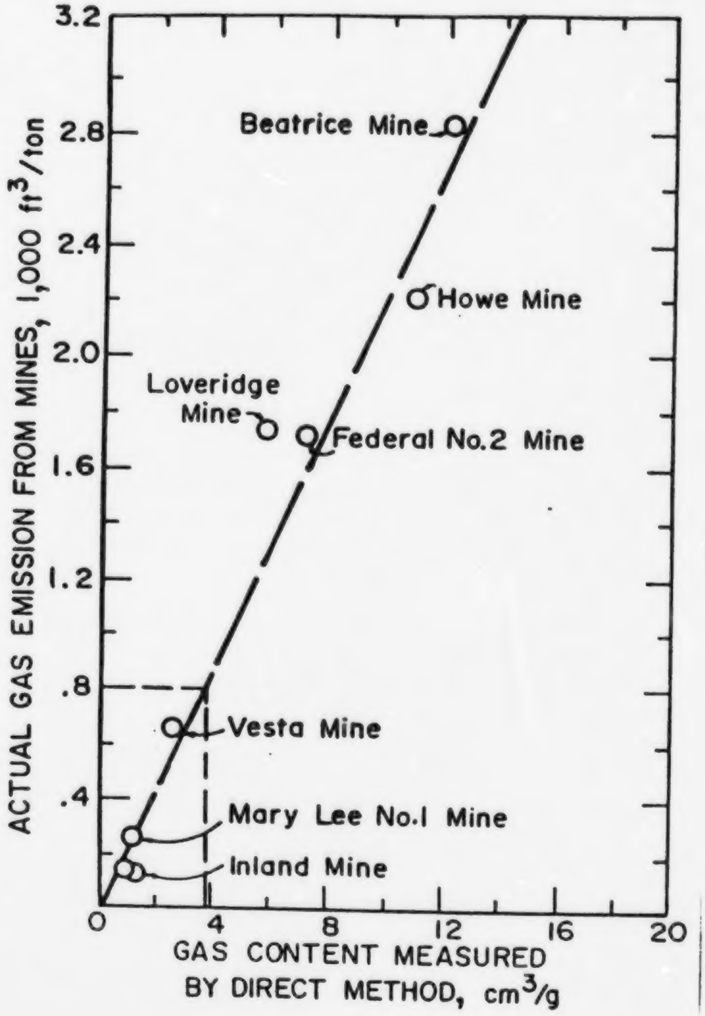


FIGURE 4-1 Comparison of Initial Content and Actual Emission - USA

Source: U.S. Bureau of Mines

SECTION 5

FUTURE WORK

SECTION 5

FUTURE WORK

5.1 INTRODUCTION

Methane prediction is only as accurate as the data base it uses. Countries using the empirical techniques reviewed in the report have been extending and enhancing their data collection methodoloy over a number of years and the improvements achieved in the accuracy of prediction reflect this work. The prediction study undertaken by Cape Breton College was hampered by lack of hard data. Assumptions had to be made to in-fill gaps in data and these assumptions affected the accuracy of prediction.

The techniques employed to obtain data are well documented and some of those techniques have been successfully applied in Canada. One of the significant features of the Sydney Coalfield that will impinge on data collection is that workings are undersea and surface borehole access will not be normally available. Data can only be obtained by direct access or with boreholes drilled from underground stations.

With the background of known data-collection technique, the immediate task is to obtain initial data required to test the MRDE prediction method. A proposed work program is depicted in Figure 5-1. The program contains a number of elements and involves both in-situ sampling and laboratory testing.

The first step is to select a suitable trial district, or trial districts, equipped with environmental monitoring equipment in which the data collection phase of the program can be implemented.

5.2 DATA GENERATION

Hard data is required for methane sources within the gas emitting zone, which for the MRDE method are coal seam sources to 200 m above and 100 m below the seam being worked. To collect these data a series of sampling programs are required.

5.2.1 Gas Content of the Seam being Worked

A sampling program, using the MRDE technique outlined by Dunmore and Creedy, should be implemented at the trial sites. Systematic sampling will, over a period of time, provide sufficient results to permit the derivation of a gas content value for the coal seam.

MRDE state this sampling procedure is not suitable for high permeability coals. It is therefore prudent to monitor the results by a series of methane content determinations from coal cores using the CERCHAR method. Selected sites for this work should be outside the zone of influence of the trial sites.

This sampling program will of necessity, be on-going. Sampling of successive working panels is essential to establish the relationship of in-situ gas content with depth. Preliminary examination of existing ventilation information (Konda, 1985) indicates a general relationship, but the regression value must be identified and this cannot be done from a surface borehole program.

5.2.2 Gas Content of Other Coal Seam Sources

Initially, this will require a cross-measure borehole program from selected sites in the Harbour Seam, to intersect the Hub and Lloyd Core seams above and the Bouthillier and Back Pit seams below. Eventually the boring program must access all seams from the Point Aconi to the Emery. However, direct access to the Lloyd Cove, Hub and Phalen seams will become available as current developments mature and will permit maintaining a tenable drilling program.

Again the direct method of gas content determination should be applied to the core samples obtained. The USBM technique has been successfully used in Western Canada (Feng, Augsten and Cheng) albeit from surface boreholes and mud-flush drilling. This technique should be incorporated into the borehole program.

A vital element in this program is selection of the correct boring equipment. Appropriate advice, where necessary, should be sought from a suitably experienced agency to ensure correct equipment selection.

5.2.3 Ventilation Surveys

Environmental monitoring equipment is essential for meaningful quantitative evaluation of methane emission. Monitoring over a suitable time period will quantify the emission into the trial district. The results obtained in this program will establish relationships regarding rates of advance, production peaks and age of district. For prediction purposes, it is essential to take into account maximum values of emission rather than mean values and the monitoring program will yield information necessary to define the co-efficient of irregularity.

In addition to the monitoring program, regular ventilation surveys are required to identify air-flow characteristics along the coal face. On modern longwall faces, equipment profiles are such that air-streaming does occur and ventilation profile surveys are required to identify this phenomenon. Work by Richards and Morris has shown that methane emitted at the coal front does not immediately mix with other air-streams on the face and the concentration of methane varies across the transverse section of the face. Mixing by diffusion may not be complete at the face-end monitoring station and the potential significance of this should be identified.

Methane migration paths must also be identified. Methane from relaxed roof and floor strata behind the face could enter the face air-stream under certain circumstances. Also, ahead of the face in the micro-fracturing zone, the induced permeability could result in some migration into the working area. Consideration should be given to a planned program of tracer gas injection to investigate migration patterns.

As the data base develops, the data should be incorporated into the prediction model to assess the effectiveness of each additional element of information. This need for a routine monitoring of the applicability of the MRDE Model is indicated in Figure 5-1. Variations between predicted and measured levels of methane emission can then be investigated in site specific circumstances, which in turn will indicate further programs to refine the basic prediction model.

5.3 RESEARCH AND DEVELOPMENT

The appropriate focus of research and development will become evident as the sampling results impact the prediction model. Basic research and development projects to be initiated in the early stages of the program should include:

- A petrographic study to identify the degree and distribution of fusinite in the seam plies at the trial sites. Creedy has found that the methane content values obtained from coal samples in close proximity to each other showed a considerable spread. Petrographic measurements indicated that a major cause of the variation was connected with the crack structure endowed on the coal lump by the constituent, fusinite. Coal lumps with high fusinite content tended to desorb gas at a considerably greater rate and hence have lower gas contents than lumps containing little fusinite. The extent to which this could impact on the sampling procedures for the Sydney Coalfield needs to be determined.

- A field and laboratory program to assess the continuity and spacing of fractures in the directions of primary and secondary cleat. Richards and Morris reported that on an active coal face, major cleat breaks were producing methane at higher rates than the remaining surfaces. This phenomenon requires investigation of the trial sites in relation to planning parameters for ventilation engineering.

5.4 ADDITIONAL PROGRAM ELEMENTS

There are two other elements in the prediction technique in addition to the gas content of coal seam sources, namely:

- Extent and geometry of the gas emitting zone and
- Degree of gas emission from sources within the zone.

The programs outlined above address the gas content of the seam being worked and other coal seam sources within the assumed gas emitting zone, in accordance with the MRDE physical model. If, as the program develops, persistent variances are observed between predicted and actual emission levels, additional investigation into the physical model must be undertaken, as follows.

5.4.1 Gas Source

The MRDE model does not include non-coal gas sources. Experience in prediction modelling in a number of countries, e.g. FRG, Poland and Belgium, has resulted in non-coal sources of gas emission being identified and included in the prediction modelling. Experience will indicate if such sources require investigation in the Sydney Coalfield. If so, an exploration borehole program must be developed to obtain data concerning strata profiles and geomechanical programs initiated to obtain the gas retention properties of those strata.

5.4.2 Gas Zone and Degree of Emission

The assumption of a rectangular zone with boundaries at 200 m above and 200 m below may prove erroneous as may the relationship between degree of emission of a given source and its distance from the seam being worked. In these circumstances, programs must be considered to refine and correct the basic model.

During the period of 1977 to 1982 Noak and Janas carried out detailed investigations into methane emissions from workings in virgin ground. This involved drilling sets of boreholes into source horizons in the zones of influence around five longwall faces. Some of the boreholes were used to determine the gas pressures and flows from methane sources. The remainder were to recover samples for the determination of residual gas content. Repeated sampling allowed the variation of residual gas content to be determined as each face advanced. The results of the investigation produced a new approach to the methane emission function. Roof boundaries of the zone of influence were found in excess of 300 m, much in excess of any previously considered. Also, the use of curves of degree of emission was replaced by a procedure using the reduction in residual gas pressure at each emitting horizon.

This technique may be capable of giving greater accuracy than other methods and must receive consideration if errors in predicted emissions from use of the MRDE technique prove unacceptably high.

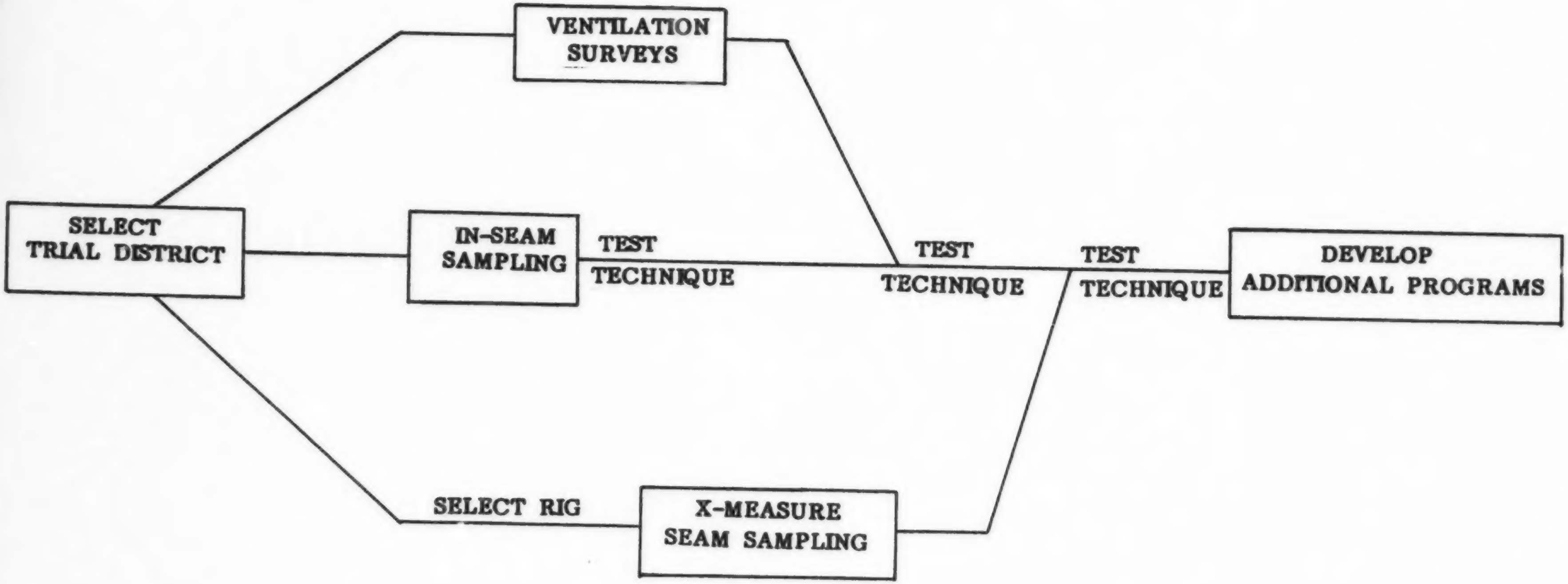


FIGURE 5-1 WORK PROGRAM FOR MRDE PREDICTION TECHNIQUE

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

1. Underground coal mining will be concentrated in the Sydney Coalfield, Nova Scotia in the immediate future, where CBDC is developing two new mines and planning a substantial uprating in annual production.

2. This increased production will come from high output longwall faces exploiting new areas of coal reserves.

3. Methane emissions into working districts are a predictable element in mining operations in the Sydney Coalfield, for both existing and planned mines and with enhanced levels of production from state-of-the-art equipment, the rate of gas emssion into working areas can be anticipated to increase.

4. The accurate prediction of gas emission will greatly assist ventilation planning and enhance safety.

5. The current stage of development, internationally in methane emission prediction affords an opportunity to select a suitable prediction model and to develop from it a reliable Canadian system without incurring heavy research and development costs.

6. The MRDE technique developed for use in the United Kingdom provides a suitable model for the development of a Canadian system for longwall mining. This prediction method is based upon a coherent physical theory. It considers the depth of the working, the age of the district and the major production control factor of rate of advance. It is the only method with a rationale for methane emisson from coal in

transit from the coal face. All these factors appear relevent in relation to Canadian mining conditions and experience.

6.2 RECOMMENDATIONS

1. A comprehensive review should be made of methane emission history in targeted districts. The review should encompass depth of working, seam thickness extracted, rates of face advance, levels of production and age of working district and the relationships of these elements with the emission levels experienced.

2. A trial working district should be selected and equipped for environmental monitoring. The district should then be used for a site-specific testing of the MRDE technique. Data generated from the monitoring program will be utilized in the prediction model.

3. A coal face sampling program should be implemented in the trial district to establish the efficiency of the MRDE direct method of determining in-situ gas content of the seam being worked. As a monitor, gas content determinations by the direct CERCHAR method should be made at selected sites.

4. A program of cross-measure boring and coring be developed to establish the in-situ gas contents of other coal seam sources.

5. Petrographic and permeability studies be undertaken to establish certain methane retention and release characteristics in the trial district.

6. That sample results be used at each stage of the program to test the MRDE technique. The numbers of assumptions to in-fill the information gaps should reduce as each program matures.

7. The degree of error obtained between predicted and measured values should be checked at each stage and should progressively reduce.

8. If the order of error is unacceptable, the geomechanical parameters of the coal seams and intermediate strata should then be fully investigated and the results in-built into the physical model of methane prediction. Goemechanical information is costly to obtain and should only be undertaken if absolutely necessary.

APPENDIX A

POROSITY AND PERMEABILITY DATA

SYDNEY COALFIELD

OFF SHORE BOREHOLE P-6 PRINCE MINE

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PAGE 2 of 2
FILE 7004-91096
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CORE ANALYSTS RESULTS

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mple mber	Depth Metres (m)	m Rep.	Sample Length m	Permeability to Air Millidarcys			Perm. x m	Porosity	Porosity x m	Density : kg/m³		Residual Saturation (Fraction of Pore Volume)		Visual Examination
				mD Max.	mD 90°	mD V				Bulk	Grain	Oil	Water	
-1	726.00-26.50	0.16	0.12	9.39	9.39	3.80	1.502	0.149	0.024	2260	2650	-	-	
-2	728.50-29.00	0.17	0.15	4.44	4.44	0.41	0.755	0.135	0.023	2290	2650	-	-	
-3	731.60-32.10	0.16	0.13	16.9	16.0	2.11	2.704	0.139	0.022	2310	2690	-	-	
-4	733.50-34.10	0.17	0.14	39.9	36.0	20.9	6.783	0.141	0.024	2320	2700	-	-	
-5	736.40-36.90	0.17	0.15	60.5	57.8	18.7	10.285	0.169	0.029	2300	2770	-	-	
-6	738.90-39.40	0.15	0.12	38.4	36.3	14.9	6.144	0.149	0.024	2290	2690	-	-	
-7	741.20-41.70	0.17	0.14	16.9	14.7	4.08	2.873	0.148	0.025	2270	2660	-	-	
-8	743.90-44.30	0.14	0.11	19.8	19.4	7.43	2.772	0.158	0.022	2250	2670	-	-	
-9	(NO DATA)	0.15	0.11	124.	117.	21.4	18.600	0.155	0.023	2290	2710	-	-	
-10	750.30-50.80	0.16	0.12	23.8	22.8	10.6	3.808	0.123	0.020	2340	2670	-	-	
-11	754.60-55.10	0.16	0.14	0.96	0.95	0.20	0.153	0.114	0.018	2380	2680	-	-	
-12	758.80-59.30	0.17	0.15	2.11	1.94	0.67	0.359	0.118	0.020	2340	2660	-	-	
-13	756.30-56.80	0.17	0.14	4.15	4.15	1.33	0.705	0.139	0.024	2300	2660	-	-	

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PAGE 2
FILE 7004-3305
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CORE ANALYSIS RESULTS

Sample Number	Depth Feet		Permeability to Air Millidarcys		Porosity Percent		Residual Saturation Oil % Pore	Residual Saturation Total Water % Pore		Visual Examination
12b-#1	486'6"		20.90		18.1		0.0	20.8		ss vf-f
12b-#2	492'0"		34.70		19.1		-	-		ss vf-f
12b-#3	493'6"		144.00		18.5		-	-		ss vf-f
12b-#4	494'10"		39.20		18.2		-	-		ss vf sl carb
12b-#5	495'0"		0.35		11.7		-	-		ss vf-f
12b-#6	497'0"		6.18		16.9		-	-		ss vf
12b-#7	498'6"		174.00		21.3		-	-		ss vf-f/m
12b-#8	500'0"		15.80		19.9		-	-		ss vf-f
12b-#9	502'0"		2.00		19.5		-	-		ss vf-f carb
12b-#10	503'6"		28.70		19.6		-	-		ss f-m/vf carb incl
12b-#11	504'6"		44.30		21.4		-	-		ss vf-f/m
12b-#12	505'0"		363.00		22.2		-	-		ss f
12b-#13	506'3"		287.00		24.9		-	-		ss f
12b-#14	507'6"		12.10		19.4		-	-		ss vf-f
12b-#15	508'0"		0.22		10.3		-	-		ss vf-f carb incl
12b-#16	492'6"		41.50		19.1		0.0	91.9		ss f
#1	965'0"		5.23		18.1		0.0	33.7		ss vf-f
12a-#2	970'0"		6.03		17.5		-	-		ss vf-f
12a-#3	974'0"		1.94		15.8		-	-		ss vf
12 -#1	945'0"		0.22		11.4		0.0	5.5		ss vf
2 -#1	2713'2"		0.15		10.2		5.1	5.1		ss vf
12a-#4	977'6"		1.91		16.4		-	-		ss m-c/f

OFF SHORE BOREHOLES H-12, H-12A, H-12B
PRINCE MINE

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PAGE 2 OF 2
FILE 7004-91035
DATE 79 11 27

CORE ANALYSIS RESULTS

Sample Number	Depth-Metres (m)	m Rep.	Permeability to Air Millidarcys Horizontal	Permeability to Air Millidarcys Vertical	Porosity	Porosity x m	Residual Saturation (Fraction of Pore Volume) Oil	Residual Saturation (Fraction of Pore Volume) Water	Grain Density kg/m³	Visual Examination
1	PM-25-1	-	0.01	0.03	0.047	-	-	-	2750	ss vf f shy fest
2	PM-25-2	-	0.02	0.01	0.069	-	-	-	2720	ss vf f
3	PM-25-3	-	0.02	0.05	0.083	-	-	-	2720	ss vf f
4	PM-25-4	-	-0.01	0.01	0.054	-	-	-	2770	ss vf f
5	PM-26-5	-	0.12	1.07	0.090	-	-	-	2770	ss vf f sl shy
6	PM-26-6	-	0.04	0.12	0.097	-	-	-	2720	ss vf f
7	PM-27-7	-	0.10	0.10	0.097	-	-	-	2710	ss vf f

PM-25 [total length of hole - 25.5 ft] - roof hole
N 35,180
W 53,325

PM-26 [total length of hole - 25.75 ft) - roof hole
N 36,970
W 53,600

PM-27

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PAGE 2 OF 2
FILE 7004-9362
DATE 1979 05 29

CORE ANALYSIS RESULTS PM-23

ple ber	Depth-Metres (m)	m Rep.	Permeability to Air Millidarcys	Permeability x m	Porosity	Porosity x m	Residual Saturation (Fraction of Pore Volume)		Grain Density kg/m3	Visual Examination
							Oil	Water		
1			0.02		0.074				2730	ss vf f sl lmy carb incl
2			0.05		0.086				2710	ss vf f sl lmy carb incl
3			0.14		0.071				2730	ss f lmy sl carb sl shy
4			0.03		0.081				2730	ss vf f lmy carb incl sl shy

PM-23 [total length of hole - 20.2 ft] - roof hole
N 32 974
W0 52 952

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CORE ANALYSIS RESULTS

Sample Number	Depth Metres (m)	m Rep.	Sample Length m	Permeability to Air Millidarcys mD Max	mD 90°	mD V	Perm. x m	Porosity	Porosity x m	Density : kg/m³ Bulk	Grain	Residual Saturation (Fractional Pore Volume) Oil	Water	Visual Examination
PM24-1A				0.04		0.04		0.103			2760			ss vf fest heavy minerals
PM24-1B				0.02		0.04		0.086			2760			ss vf fest heavy minerals
PM24-2A				0.10		0.09		0.114			2770			ss vf fest heavy minerals
PM24-2B				0.13		0.11		0.102			2770			ss vf fest carb heavy miner.
PM24-3A				0.12		0.09		0.111			2770			ss vf fest carb bands heavy minerals
PM24-3B				0.07		0.07		0.095			2770			ss vf fest carb heavy minerals
PM24-4A				0.18		0.16		0.108			2750			ss vf fest heavy minerals
PM24-4B				0.19		0.19		0.120			2750			ss vf fest carb bands heavy minerals
PM24-5A				0.05		0.04		0.096			2760			ss vf fest sl shy heavy minerals
PM24-5B				0.08		0.05		0.102			2760			ss vf fest heavy minerals
12-5-4A				0.02		0.02		0.040			2710			ss vf sl shy v sl lmy
12-5-4B				0.08		0.09		0.050			2710			ss vf sl shy v sl lmy

PM-24 [Total length of hole - 21.2 ft] - root hole
N 34,322
WE 53,370

These analyses, opinions or interpretations are based on observations and materials supplied by the client to whom, and for whose exclusive and confidential use, this report is made. The interpretations or opinions expressed represent the best judgment of Core Laboratories - Canada Ltd. (all errors and omissions excepted); but Core Laboratories - Canada Ltd. and its officers and employees, assume no responsibility and make no warranty or representations as to the productivity, proper operation, or profitableness of any oil, gas or other mineral, well or sand in connection with which such report is used or relied upon.

1075

CORE LOG

page ../3

Date June 22, 1979

NTERVAL	THICKNESS	ROCK TYPE	COLOR	DESCRIPTION	DIP
		Permeability ~~To Air~~ Millidarcys	Porosity %	-Samples removed for Porosity and Permeability Measurements	
27- 30"	PM-25-1				
69- 72"	PM-25-2				
90- 92"	PM-25-3				
106-109"	PM-25-4				
125-128"	PM-25-5				
162-164"	PM-25-6				
184-187"	PM-25-7				
				Note:-	
				Benezedine Test performed on immediate roof.	
				Test negative.	
				Core stored: Point Edward	
Note:					
76- 79")	Samples taken				
149-152")	for office				
206-210")	Reference.				
	F.M.I.				

CORE LABORATORIES – CANADA LTD.

COMPANY CAPE BRETON DEVELOPMENT CORPORATION
WELL CAPE BRETON SELECTED SAMPLES
LOCATION

FORMATION
ANALYSTS KK SA DH

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CORE ANALYSIS RESULTS

Sample Number	Depth-Metres (m)	m Rep.	Permeability to Air Millidarcys	Permeability x m	Porosity	Porosity x m	Residual Saturation (Fraction of Pore Volume)		Grain Density kg/m³	Visual Examination
							Oil	Water		
1A	Horizontal Perm.	-	-0.01	-	0.036	-	-	-	2810	ss f m c pbls sl shy pyr
1B	Vertical Perm.	-	-0.01	-	0.038	-	-	-	2840	ss f m c pbls pyr
2A	Horizontal Perm.	-	-0.01	-	0.010	-	-	-	2630	ss vf f sl carb shy
2B	Vertical Perm.	-	-0.01	-	0.010	-	-	-	2620	ss vf f sl carb shy
3A	Horizontal Perm.	-	-0.01	-	0.038	-	-	-	2700	ss vf f sl shy
3B	Vertical Perm.	-	-0.01	-	0.034	-	-	-	2690	ss vf f sl shy
4A	Horizontal Perm.	-	0.05	-	0.070	-	-	-	2690	ss vf f
4B	Vertical Perm.	-	0.11	-	0.069	-	-	-	2690	ss vf f
5A	Horizontal Perm.	-	0.02	-	0.041	-	-	-	2680	ss vf f
5B	Vertical Perm.	-	0.05	-	0.046	-	-	-	2670	ss vf f carb sl fest
6A	Horizontal Perm.	-	0.16	-	0.079	-	-	-	2700	ss vf f sl fest
6B	Vertical Perm.	-	0.26	-	0.079	-	-	-	2680	ss vf f

1A & 1B - LINGAN MINE - 5 EAST - Sandstone - roof
2A & 2B - No. 26 - 13 South - Floor
3A & 3B - Lingan Mine - Room & Pillar - floor
4A & 4B - No. 26 - 12 South - 12 South - roof
5A & 5B - Lingan - roof
6A & 6B - Lingan - 1 west - roof

APPENDIX B

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